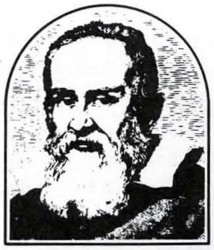


The Galileo Messenger

1625-101, ISSUE 1 APRIL 10, 1981

FROM THE PROJECT MANAGER

After a flurry of activity during the last three months the Galileo mission has again stabilized. It is important at this juncture that we avoid the tendency to listen to rumors, which will be rampant a few more months, and to concentrate on our specific tasks. Detailed budgets and schedules for the 1985 launch have been developed and these must now be carefully analyzed for consistency and practicality. Some fine tuning may be necessary in this coming quarter. Despite the fact that the launch has been delayed for a year, the recombining of the Probe and Orbiter, together with the new Centaur interface, provides enough new and additional design challenges. As a consequence of this and our firm resolve to keep the development activities going on the '84 schedule in order to minimize cost, there is no additional slack in the schedule.

I would also like to remind all of you, especially those of you who may be depressed because you have now seen the launch date slip twice, that Galileo has received extraordinary support during the recent budgetary discussions with the new administration. Galileo is now the sole surviving planetary mission in the NASA program. We carry with us the legacy of the great exploratory journeys of the past two decades. It is now up to us to redouble our dedication, to show that the recent vote of confidence in Galileo is well-placed.

– J. R. Casani

MEET THE TEAM: Tom Gavin

As Project Galileo's Reliability and Quality Assurance Manager, Tom Gavin's fundamental responsibility is to ensure that all elements of the spacecraft, including both the hardware and the software, meet a set of uniform standards for design, development, manufacture, and test. With Tom's leadership, the R&QA office played the lead role in initially defining these standards for the project and now provides regular assessments on how well each spacecraft subsystem is meeting the standards. By checking compliance with the predefined standards, the R&QA Office essentially serves as the quality conscience of the Project.

Tom says his biggest challenge on Galileo is keeping track of all the new developments; that is, those subsystems or elements of the spacecraft that are not similar to subsystems on previous JPL spacecraft. These new developments, such as the spin bearing assembly that connects the two major sections of the Orbiter and the small computers called microprocessors that are scattered all over the spacecraft, involve new parts and new technologies that previously had not been subjected to the rigorous standards required for use by Project Galileo.

Tom lives in Canyon Country, between Newhall and Palmdale, with his wife Betty and four children, aged eleven to nineteen. He is very active in youth activities, especially baseball and other sports that permit him to spend lots of time with his children.

Tom is a gentle, gracious man who thinks carefully before he speaks. When he does offer an opinion, the quality of his remarks would pass even the most rigorous standards.

Tom Gavin

THE MESSENGER

The Galileo Messenger will be a combined project newspaper and status bulletin. Its purpose is to provide both a summary of the project activities and an informal set of feature articles highlighting specific aspects of the project. We hope that the *Messenger* will convey not just the facts associated with Galileo, but also something more subjective, an exciting look at the nature of the Galileo endeavor.

The *Messenger* will be published quarterly, between two weeks and one month after each quarterly review. It will carry several standard features, including a short status-oriented message from the Project Manager, a presentation of one of the Galileo science experiments, and an in-depth discussion of an important (and recent) engineering activity. In each issue there will also be a capsule profile of a key Galileo team member and an explanation of a significant facet in the mission design. The final standard feature will be **Potpourri**, a column about the people and activities of the project written in a "stream-of-consciousness" style by Gentry Lee.

It is anticipated that the *Messenger* will evolve quite rapidly in the beginning. We solicit comments from all members of the Galileo community, including the families and friends of those directly involved in the project.

One final note on the name: The phrase *"The Starry Messenger"* has become synonymous with Galileo the man, not only because of his book of that title, but also because of the excellent episode on Galileo in Jacob Bronowski's *"The Ascent of Man."* It seems altogether fitting that this newspaper/ status bulletin retain the close identification with one of the astronomical giants of history.

THE 1985 GALILEO MISSION DESIGN

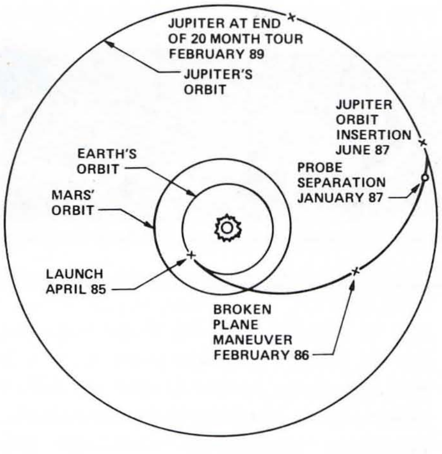
As a result of recent management reviews of the entire NASA program, the Galileo mission will now be launched in 1985. The delay in launch year is only one of many substantive changes in the Galileo mission design. Although some of the details have not yet been determined, the mission design for the 1985 mission that is emerging differs markedly from the old baseline mission, which assumed two separate launches in 1984.

The biggest change, of course, is that the Galileo Orbiter and Probe now fly to Jupiter as a single spacecraft again, just as they did when the Project was originally conceived. Thus, there is no requirement for two Shuttle launches or for a Probe Carrier spacecraft. Another major change is in the launch system. The rocket that will ride into orbit in the Shuttle payload bay and then insert the combined Galileo spacecraft on its trajectory toward Jupiter is no longer the three-stage Inertial Upper Stage (IUS). The upper stage rocket will now be a modified Centaur.

The projected launch for Galileo is now in April of 1985. For the 1985 mission there is no close encounter with Mars on the way to Jupiter. There is, however, what is called a "broken plane" maneuver that is expected to take place about ten months after launch, in February of 1986. By using the broken plane maneuver (the name derives from the fact that there is a change in the plane of the trajectory at the time of the maneuver) valuable spacecraft fuel is conserved for use later in the mission.

The likely time of encounter with Jupiter for the 1985 Galileo mission ranges from early June to late September of 1987, depending upon the exact launch date and the trajectory selection strategy. Whatever the encounter date is, the Galileo Probe will be separated from the Orbiter about 150 days before encounter and the Orbiter deflection maneuver will occur about three days later. The Orbiter deflection maneuver moves the Orbiter off a path that would enter the Jovian atmosphere and establishes the key geometry for both the Probe-Orbiter relay link and the Jupiter Orbit Insertion (JOI) maneuver.

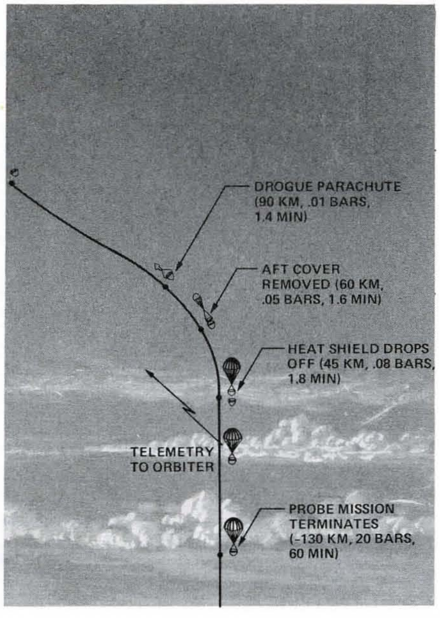
The Orbiter places the Probe on its entry trajectory and spin-stabilizes it in



Mission Plan

its proper attitude for entry into the Jovian atmosphere. Once the Orbiter and Probe are separated, the Probe is on its own. It cannot receive commands. The Probe entry sequence, which will record scientific data about the upper atmosphere of Jupiter, is started on a timed command (there is also an acceleration sensor that backs up this critical command). The Probe hits the atmosphere of Jupiter at the incredible speed of 108,000 miles per hour, by far the fastest entry yet attempted in any space mission. Once the protective aeroshell that encapsulates the Probe during this severe entry heating has been jettisoned, the Probe descends on a parachute.

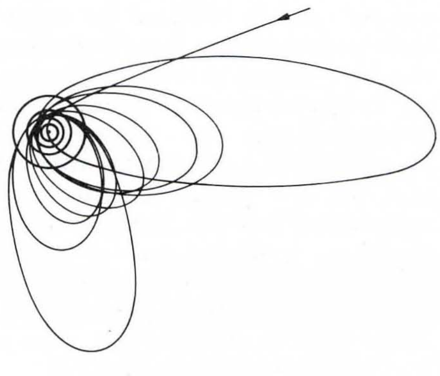
During the descent, which may last as long as one hour before the Probe perishes, six different science instruments are taking data that characterize the atmosphere of Jupiter. Both the



Probe Descent

exact chemical composition and the pressure and density of the atmosphere are among the quantities that will be determined by the sophisticated flying laboratory carried on the Probe. All the scientific data acquired by the Probe are transmitted to the Orbiter flying overhead. From the Orbiter the data are then sent to the Earth.

The Orbiter, meanwhile, after carefully serving as a relay station for the Probe and burning its retropropulsion engine to achieve an orbit about Jupiter, then continues its own mission, which lasts for twenty more months. During that time the Orbiter will characterize the magnetic field of Jupiter and make eleven close flybys of the four intriguing Galilean satellites – Io, Europa, Ganymede, and Callisto.



Satellite Tour

At the present time there is some concern that the previous baseline mission for the Orbiter, which involved an extremely close flyby of Io around the time of Jupiter encounter, might unduly jeopardize the remainder of the Orbiter mission. An Io flyby requires that the spacecraft come in very close to Jupiter and spend considerable time in a radiation hazard zone. As a result, current studies are focusing not only on whether observations of Io should take place before or after the relay link/orbit insertion sequence, but also on what kind of Orbiter mission would result if all Jupiter encounter activities were moved some distance away from Jupiter and Io to avoid the worst radiation zones. In that case, a close Io encounter might be scheduled later in the mission.

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THE ATMOSPHERE STRUCTURE EXPERIMENT

The main purpose of the atmosphere structure experiment, which is part of the Galileo Probe science package, is determination of the characteristics of the Jovian atmosphere as a function of changes in altitude. By directly measuring not only the temperature and pressure during the Probe's descent through the atmosphere of Jupiter, but also the aerodynamic deceleration force throughout the same period, the experiment obtains all the raw data needed to compute the pressure, temperature, and density of the atmosphere as a function of altitude.

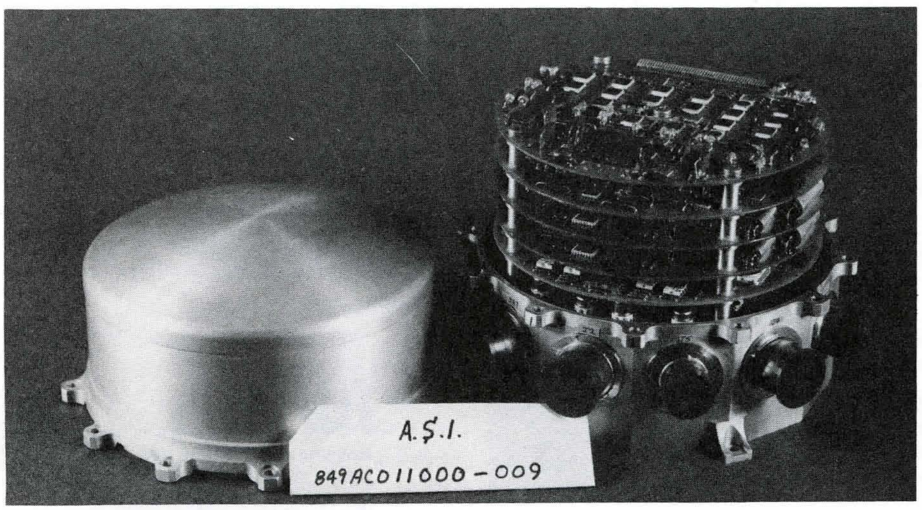
The resulting picture of the Jovian atmosphere that will emerge after the data from the atmospheric structure experiment are processed will be carefully compared with the range of currently existing, pre-Galileo models of Jupiter's atmosphere. These existing models are based both on remote sensing observations (such as those taken by Pioneer and Voyager) and on theoretical ideas about the likely internal structure of the atmospheres of the outer planets. It appears virtually certain that the detailed data from the structure experiment will force considerable modifications to even the most accurate of these pre-Galileo models.

The atmosphere of Jupiter that will be determined by the atmospheric structure instrument should be detailed enough to answer questions about the existence of local turbulent patches in the atmosphere, the magnitudes of vertical winds, and the altitudes at which phase changes (from gas to liquid or vice

Al Seiff

versa) of the key cloud-forming constituents take place. It may even be possible, if stable regions in the atmosphere are identified by the structure experiment, to detect gravity waves.

Essentially, the atmospheric structure experiment is three sensors (measuring pressure, temperature, and acceleration) together with an electronics package to control the experiment sequences and prepare the data, after it is acquired, for transmission to the Galileo Orbiter and eventually to Earth. The experiment sequences, which define the exact time and number of independent observations that are taken by the sensors, are carefully established so that the fine structure of the atmosphere can be deduced. For example, once the Probe is well into the atmosphere, during the key descent phase, independent pressure and temperature observations are taken every two seconds. During the same period the key accelerometer channel located along the primary body axis of the Probe is sampled every sixteen seconds.



Atmosphere Structure Experiment

The principal investigator for the atmosphere structure experiment is Al Seiff of Ames Research Center, a veteran of many deep space missions. Al feels that the poorly characterized and possibly hazardous environment of Jupiter is his biggest potential problem. He worries that the temperature sensors and electronics may be adversely affected by the passage of the Probe through the clouds, during which time the entire probe may be charged to tens of kilovolts. As for the instrument itself, which is being built by the Martin Marietta Corporation in Denver, Al does not foresee any fundamental problems.

POTPOURRI

The recent change in government has produced more than the usual tremors in the budgetary process. . . . the first detailed budget developed by Mr. Stockman included the cancellation of Galileo . . . . ouch and double ouch . . what would be worse than only one funded planetary mission . . . none at all, none at all . . . Fortunately for those of us who are space junkies there were many key people who screamed as soon as word of the possible cancellation of Galileo "leaked" to the press. . . the final budget submitted to Congress by the new President did include monies for the continuation of the Project.

Option City. . . that's what it has been like in the Galileo offices for the past three months . . . for those of you who haven't been following closely, the baseline mission is now a 1985 combined launch of the Probe and Orbiter, using a Space Transportation System (STS) equipped with a "fat" Centaur. . . the Centaur will give the spacecraft its needed boost to escape the gravitational attraction of the Earth. . . the three-stage Inertial Upper Stage (IUS), once the all-purpose vehicle for sending planetary payloads on their way, will now not be used for planetary missions. . . it is difficult if not impossible to keep Project activities "on track" when programmatic considerations force analysis of many different options. . . much of the management talent must necessarily be involved in the analysis of options. . . so the baseline work does not receive its normal amount of attention. . . let's hope that Option City is now closed and we can concentrate on the design of the mission and spacecraft for the 1985 mission.

(contd)

THE SPIN BEARING ASSEMBLY

The spin bearing assembly (SBA) is the device that mechanically couples the two parts of the Galileo Orbiter. It ties together the part of the Orbiter that is spinning all the time and the "despun" or non-spinning portion of the spacecraft. The critical remote sensing instruments, including the imaging system, are mounted on the despun section of the Galileo Orbiter and must be both fixed in space and accurately pointed during their key observation periods.

The functions of the SBA are straightforward. Upon command from the attitude control computer, the SBA motor imparts torque to the "despun" side to drive it to the proper angular orientation for observations. The SBA also is the device by which power and data/information are electrically transferred back and forth between the two sections of the Orbiter. Finally, because the spin bearing assembly is on the spin-axis of the spacecraft (the spin axis is an imaginary line around which the spacecraft rotates when it is spinning) and because of the need for very accurate rocket thrust vector control when the orbit insertion engine is fired, the SBA provides, as part of its mechanical structure, a path for the retropropulsion engine's propellant-containing tubes.

The spin bearing assembly is one of the most critical engineering subsystems on the Galileo Orbiter. Project Policy 17, the "Single Point Failure" policy, specifies that any single component or element of the spacecraft whose failure would preclude achievement of the mission objectives must be redundant. Although the SBA features redundant *components* throughout its design, including redundant torque motors, electronics, etc., the SBA is a major exception to the single point failure policy. Even though failure of the SBA would mean almost total degradation of the remote sensing data, there is no practical way to provide two entirely separate assemblies. Hence, the reliability of the SBA design is extremely critical.

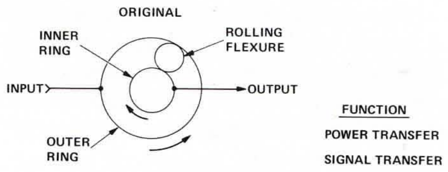
The initial design of the SBA involved a new technique for accomplishing the power and data transfers between the two parts of the Orbiter. Since one part is spinning with respect to the other, cables cannot be used; they would soon become wrapped around the joint that connects the two parts. The initial subsystem design used a roll ring concept that appeared to have outstanding advantages (little or no friction, lightweight, easy to make) over more tested approaches. In the roll ring design a hundred identical little rolling hoops, about the size of wedding rings, rolled around in channels between two concentric rings, each of which was electrically connected to one of the two distinct sides of the spacecraft. Power and data transfers were thus accomplished through these rolling rings.

This design turned out to have unexpected problems. Soon after the first tests were begun, two problems with the roll ring design became clear. First, since the assembly squeezed the little hoops into ellipses (to keep them rolling in the proper channels), eventually the hoops would break. Secondly, and even more important, the electrical contacts developed by the roll rings were not good enough to keep the quality of the signal being transferred above the acceptable error tolerances. Thus some "noise" was being introduced in the transfer between the two sides and this noise could disastrously alter the scientific or engineering data.

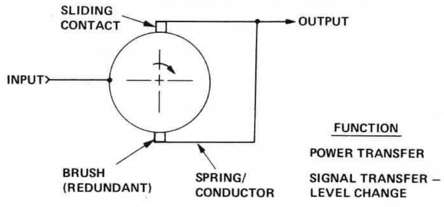
At this point the Galileo Project formed an interdisciplinary "tiger team", headed by Joe Savino, to study the roll ring problems, recommend solutions if available, and develop possible alternative designs to implement the power and information transfers. Although the team did find ways of ameliorating the difficulties (for example, lubricating the roll rings does significantly reduce the noise characteristics), on December 17, 1980 they recommended (and the Project accepted) a design change for the SBA.

The new power/data transfer system has two separate parts. The power transfer is accomplished by what are known as slip rings, a device that has been used in spacecraft before. With the slip rings, a fixed brush contact drags on a large revolving ring that is electrically connected to the spinning side. Although the brush produces debris and is subject to wear, these characteristics have been measured in similar systems and are fairly well understood.

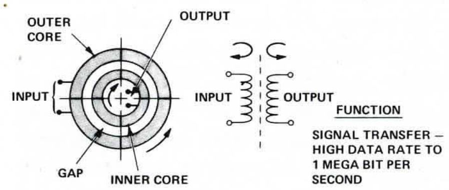
The new data transfer system for the SBA involves what is called a rotary transformer. In this design, coiled wires are electrically connected to each of the two sections of the Galileo Orbiter. Signals pass between the coils (although they are not in physical contact) by means of the magnetic field generated by the current in the coils. This technique also has been tested in previously flown spacecraft.



Roll Rings — Original Design



Slip Rings — Present System



Present System — Rotary Transformers

POTPOURRI (contd)

Optimisim Department. . . Dick Spehalski manages the Spacecraft Integration Office and has been on the project for over three years. . . he will request a parking place near Building 169 where Galileo is housed when he is convinced that the Project is for real. . . who can blame him? After three years plus we are still as far from the launch date as we were when the Project office was established. . . Ron Draper has lost count of how many times the spacecraft configuration has changed since October 1977. . . but the dream remains. . . and it's a dream worth pursuing.

Changing of the guard. . . Bill Shipley has left the project to run JPL's Quality Assurance and Reliability Office. . . Ron Draper has taken over as manager of the Orbiter Office. . . Bill will be missed.

—Gentry Lee

NASA
National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

The Galileo Messenger

1625-101, ISSUE 2 JULY 10, 1981

FROM THE PROJECT MANAGER

During the last quarter the Galileo Project held its annual detailed cost review for Headquarters. This was the first cost review since the baseline mission was changed to a 1985 launch using a Centaur as the upper stage. The Headquarter's review team, reflecting the budgetary emphasis of the new administration, were keenly interested in all phases of the costs. The review went very well, but there is clearly a very serious attitude about Galileo costs at NASA Headquarters. As a group we must make certain that we understand all our costs and be committed to them, division by division, subcontractor by subcontractor.

There have been times in the history of the space program when technical excellence and ensuring specifications were regarded as much more important than meeting budgets. Those times have passed. In a very real sense Galileo has made a fixed price commitment to NASA Headquarters and the new administration. Support for Galileo is evident at all levels of NASA management, but *only* at the established cost level. It is virtually certain that any significant cost overrun would undermine our support and could lead to cancellation.

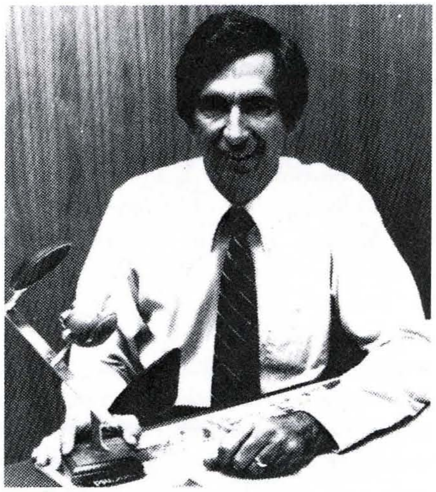
What this cost emphasis means to each of us is obvious. First, planned work must be accomplished on schedule, even when missing the schedules will not impact subsequent major milestones such as SAF delivery or launch. The reprogramming actions that we have been through have created many situations where the work schedules are not on the critical path for launch. This was done deliberately to minimize the cost of the reprogramming actions. To realize these cost savings and to prevent further cost increases, we must be tough minded about schedule accomplishment. Second, if certain areas of our work require more money, then we must, *at the same time*, identify offset areas where work and costs can be reduced. In some cases this may mean reassessing already existing specifications and policies. Although such reassessment is painful, it is absolutely necessary in the current environment. A Galileo mission that accomplishes less than one hundred percent of the current objectives is far better than no mission at all.

I ask each of you to join with me in increasing the cost consciousness of the Project at all levels.

— John R. Casani

MEET THE TEAM:

An imposing figure at significant Galileo meetings is the two-meter man from Ames, Mr. Nick Vojvodich. Nick is the Deputy Manager of the Galileo Probe and is the primary technical interface between the Probe Office at the Ames Research Center and JPL. Nick's other main role on the project is the integration of the heat shield design for the Probe. Much of the heat shield analysis is done by heat shield specialists at Ames; Nick must make certain that the results of this analytic work are properly included in the actual Probe design done by General Electric and Hughes.



Nick Vojvodich

Nick joined the Ames Research Center in 1958 after finishing a master's degree at Stanford in aeronautics and astronautics. For the past ten years he has managed entry probe related structures, beginning with Pioneer Venus and continuing through the outer planets probe design study that was a precursor to Galileo.

A varsity basketball player at Stanford, Nick stays active by playing tennis. He and his wife Helen have four daughters, twins Catherine and Coleen (21), Kim (19), and Lynn (13). Nick admits to having a keen interest in history. His Galileo presentations reflect his historical interest — rich in detail, full of facts, and replete with interpretations.

THE RELAY LINK

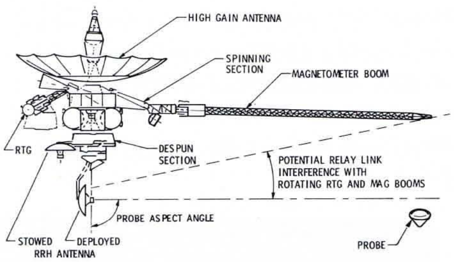
When the Galileo Probe enters the atmosphere of Jupiter, the scientific and engineering data that it acquires is transmitted to the Orbiter. The Orbiter then transmits this data back to Earth. The engineering subsystem that is designed to ensure that the Probe data safely and accurately goes from the Probe to the Orbiter is called the relay link.

The old baseline Galileo mission called for two launches in 1984. In that mission, the Probe traveled to Jupiter on a special vehicle known as the Probe Carrier. The Probe Carrier made certain that the Probe was placed on the proper entry path and then served the Probe additionally by relaying the Probe data back to Earth. The Probe Carrier design was optimized in terms of its Probe support characteristics.

When the baseline mission changed to a 1985 launch, the Galileo Probe and Orbiter were once more combined (as they had been originally when the launch was scheduled for 1982) into a single spacecraft. The Probe data is relayed through the Orbiter near the

time periods when the Orbiter is itself acquiring valuable scientific data and when it is preparing for its largest maneuver, the Jupiter Orbit Insertion (JOI). Thus, the relay link cannot be designed solely to optimize the return of the Probe data; it must also take into account the competing characteristics of the Orbiter mission design.

During the preliminary work on the 1982 Galileo mission, a relay link design was selected that appeared to meet all the requirements of both the Probe and the Orbiter. When the two vehicles were recombined for the proposed 1985 launch, the first thought was to use the relay link design that had been selected for the original 1982 launch. There were several reasons why this approach of using the old design turned out to be unworkable.



In the first place, detailed analysis of the old design turned up some significant factors that had been omitted in the preliminary design of the relay link. These factors all by themselves made the old design marginal. Secondly, and more important, the 1985 mission geometry at Probe entry is significantly different from that which would have occurred if the launch had been in 1982. As a result, a critical angle called the Orbiter aspect angle, which relates the Probe at the time of its entry to the orientation of the Orbiter, changed from 55° to about 90°. This change in aspect angle meant that the old location of the relay antenna on the Orbiter, which had enjoyed an unobstructed view of the Probe for the 1982 mission, was no longer valid. If the relay antenna were placed in the same location for the 1985 mission, then the Orbiter magnetometer boom and two RTG booms would rotate through the line of sight between the Probe and the relay antenna and possibly interfere with the data link between the Probe and the Orbiter.

Other factors also played a role in the new design of the relay link. Concern about possibly damaging electrostatic discharge events in the neighborhood of Jupiter suggested that it might be a good idea to move the Orbiter away from Jupiter during the time of the relay from the Probe. In addition, worry that perhaps the star-scanner might not work in close to Jupiter suggested minimizing the number of spacecraft turns that would be needed to accomplish the major activities of relay data acquisition, Jupiter orbit insertion, and Io science data acquisition.

During the last three months on the Galileo project, one of the major activities has been the determination of the relay link design for the new mission. A number of options were studied. Essentially these options divided into two families. One family of options involved adding an L-Band feed to the high gain antenna on the Orbiter and using the high gain antenna as a relay receiving antenna. The other family of options employed a side-looking or aft-facing receiving antenna designed specifically for the relay link.

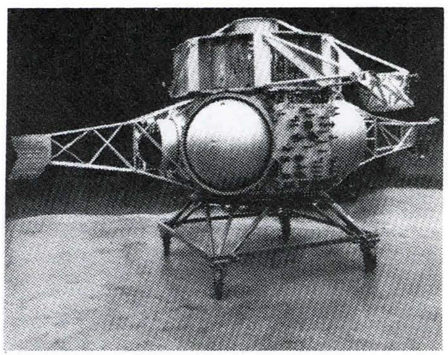
The options involving use of the high gain antenna were discarded first, primarily because of severe link degradation in the presence of pointing errors. An aft-pointing relay antenna would have required the Galileo spacecraft to make a large turn just before the relay link and another just after, both of which would take place at a distance from Jupiter where the critical star-scanner's performance is questionable. So the side-looking relay receiver configuration was eventually selected.

The baseline relay link design, which is still being fine-tuned, consists of a side-looking antenna mounted on a small motor-driven boom. The antenna is circular, with a diameter of 1.1 meters. With this antenna, all three major activities during the Jupiter encounter – Io science data acquisition, relay data acquisition, and the JOI maneuver – can be done in a fixed attitude with unbroken communications to the Earth.

THE RETRO-PROPULSION MODULE (RPM)

One of the interesting features of the Galileo project is that the propulsion system is built in the Federal Republic of Germany. The company that builds the Retro-Propulsion Module (RPM) is Messerschmitt-Bölkow-Blohm (MBB) in Ottobrunn, near Munich. MBB built the propulsion unit for the French-German Symphonie Spacecraft and the Galileo RPM uses engine technology derived from that project. Day-to-day management of the MBB activity is by the DFVLR (Deutsche Forschungs- und Versuchsanstalt fur Luft- und Raumfahrt e.V.), a German research agency under the aegis of the German ministry for research and technology. JPL engineers communicate directly with their MBB counterparts on technical issues. However, all technical direction is through DFVLR to MBB.

The RPM performs two major functions in the Galileo mission. First, using its large 400 Newton engine, it provides the thrust for all major Orbiter maneuvers, including the orbit deflection after the Probe has been released, the Jupiter Orbit Insertion (JOI) maneuver, and the Perijove Raise Maneuver (PRM) while in orbit around Jupiter. Secondly, the RPM provides all the thrust for attitude control and trajectory corrections of the Galileo spacecraft. It uses its 10 Newton engines to accomplish changes in attitude and spacecraft spin rate. Because of its sheer size (210 kilograms of dry weight which can be loaded with up to 935 kilograms of propellant – when fully loaded the RPM is almost half the weight of the



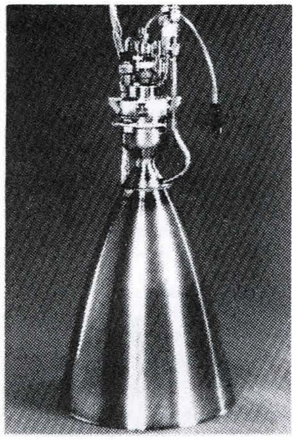
THE RETRO-PROPULSION MODULE (RPM)

entire spacecraft), the RPM is also a very important element in the overall design of the Galileo configuration.

In looking at the configuration drawings, one feature is immediately obvious. There is only one 400 Newton engine. It must work at the appointed time to ensure that the Galileo Orbiter will successfully achieve an orbit about Jupiter. If the RPM were to fail to operate at the specified time, then Galileo would sail on by Jupiter, its battery of instruments never able to perform their desired experiments.

Preparations for use of the 400 Newton engine begin very early. Three months before launch, while the spacecraft is at Kennedy Space Center, the helium pressurization gas and the propellants are loaded. Both size engines will later use the two propellants that are loaded at the Cape. The two liquid propellants, monomethyl hydrazine ($N_2H_3CH_3$) and nitrogen tetroxide (N_2O_4), are stored in four separate tanks (two tanks for each propellant) and are lightly pressurized by helium. After the launch of Galileo, during the cruise phase of the mission, the 400 Newton engine is carefully prepared for operation. First the plumbing is cleared of residual gases by a venting process. Next the propulsion system isolation valves, which were hermetically sealed during the launch phase, are opened so that the propellants can drop down to the engine inlet. The propellant tanks are then raised to the operating pressure of 260 pounds per square inch by introducing additional helium.

The actual implementation of a large Galileo maneuver, such as JOI, begins by establishing the proper attitude and spin rate for the maneuver. To do this, the attitude control system uses the 10 Newton engines of the RPM for thrust to position the spacecraft in attitude. Then the attitude control computer sends a signal to the RPM that opens valves and allows both propellants to flow into the engine combustion chamber. In the chamber the propellants ignite spontaneously (such propellants are called hypergolic propellants) and the resultant hot gases rush out through the throat of the engine. It is the acceleration of the gases through the throat that provides the needed thrust to the spacecraft.



THE RPM's 400-NEWTON ENGINE

Once the engine valves are opened to admit the two propellants, the only active control on the propulsion system is the helium gas regulator which maintains a constant propellant feed pressure to the combustion chamber. The attitude control accelerometer measures the accumulated thrust and closes the engine valves when the proper change in velocity has been imparted.

The JOI maneuver for Galileo involves an engine burn duration of forty-five minutes or so. None of the maneuvers on the French-German Symphonie spacecraft required such a long burn. Thus, one of the major goals of the Galileo engine test program is to verify the behavior of the RPM system during long burns.

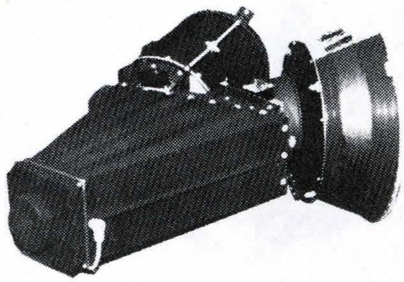
The design of the RPM is proceeding without undue difficulty. At the beginning of the Galileo project, of course, the pace was very slow because the engineering organizations on both sides of the Atlantic were still learning how to work with each other. Now the communications between JPL and DFVLR/MBB have greatly improved. In this era of increasingly tight NASA budgets, it may well be that international cooperation will be a necessity on future large space projects. If so, the successful American and German experience on Galileo may be viewed as the prototype for that cooperation.

Oops! — In our first issue we told you all about the Spin Bearing Assembly except who's designing and fabricating it. Our apologies to Sperry Flight Systems, Phoenix, AZ.

THE NEAR-INFRARED MAPPING SPECTROMETER (NIMS)

The Galileo Near-Infrared Mapping Spectrometer (NIMS) has two major objectives. The first objective is to look at the surfaces of the satellites of Jupiter to determine their chemical composition. The second objective is to study the atmosphere of Jupiter to determine such things as the characteristics of the Jovian cloud layers, the spatial and temporal variations in the constituents of the atmosphere, and the temperature vs. altitude profiles in the region of the atmosphere between one bar (the Earth's atmospheric pressure at sea level) and five bars.

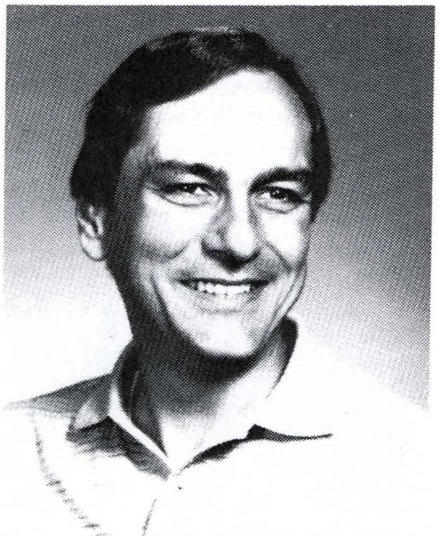
The first objective essentially is to answer the question, "What are the moons of Jupiter made of?" We already know, from ground-based observations, that there is sulfur dioxide (SO_2) on the surface of Io and water frost covering most of the other three Galilean satellites. But what is the dirty stuff, for example, that is mixed with the ice on Callisto? The NIMS has the capability of recognizing and classifying silicates, carbonates, nitrates, and other compounds that are the most likely candidates for the dirt in the snowballs of Callisto. One of the results of the NIMS observations will be a map of each satellite with identified compositional units. Using such a "geological" map, one would be able to tell at a glance what kinds of surface materials are located in which areas of the moons. These data will then be compared, satellite to satellite, and even Jovian satellites to other moons and asteroids, in an attempt to gain additional insight into the processes governing the evolution of the solar system.



THE NEAR-INFRARED MAPPING SPECTROMETER (NIMS)

In meeting the second objective, the NIMS will provide data that will help answer fundamental questions about the Jovian atmosphere. One result from the NIMS experiment should be a definition of cloud thicknesses and identification of layers of clouds as a function of depth in the Jovian atmosphere. Also, ground-based telescope measurements and Voyager have observed a number of free molecular species in the atmosphere of Jupiter, including water (H_2O), ammonia (NH_3), phosphine (PH_3), and the exotic germane (GeH_4). Repeated studies by the NIMS will focus on the variations of the abundance of each of these species as a function of time of day and Jovian season. Variations in these species should give clues about the atmospheric chemistry and dynamics. A final NIMS atmospheric objective, which is useful when mapping a region with no high clouds, is to determine the thermal profiles in the one to five bar range. The Galileo photopolarimeter will be able to ascertain thermal profiles in the atmosphere above one bar. By examining relatively cloud-free regions, NIMS can extend the thermal information down to five bars.

The Galileo NIMS is a brand new instrument. Nothing like it has ever flown before in space. It was selected because the near-infrared region of the electromagnetic spectrum [a region that begins with the deepest red your eyes can see (0.7 microns wavelength) and then moves out of the visible to wavelengths of 5 microns] is powerfully diagnostic for gaseous species and solid state reflection characteristics. For these reasons, the NIMS is great for determining what is in the atmosphere of Jupiter and on the surface of the Jovian moons.



Dr. Robert Carlson

The NIMS consists primarily of a telescope and a spectrometer. The telescope directs the light into the spectrometer, which then acts like a prism and separates the individual "colors" (i.e., wavelengths) in the near-infrared. An array of detectors measures the intensity of response at each individual wavelength and these data then form the spectrum of the area under observation. From this spectrum, which is made up of all the responses throughout the infrared region, the quantity and composition of the material or gas being observed can be deduced. Actually, because of a vast data bank of information on characteristic spectral signatures that is readily available, it is reasonable straightforward to identify what chemical compounds have been observed. It is a more subtle and more difficult process to extract from the spectra the answer to the question, "How much of each species was seen?"

The NIMS instrument is being built at JPL; and the engineering model is presently undergoing testing in the thermal-vacuum chamber. The principal investigator is Dr. Robert Carlson of JPL. He is supported on the NIMS team by thirteen other scientists from the U.S., England, and France.

POTPOURRI

In little more than a month, the second Voyager spacecraft will encounter Saturn and the world will again thrill to the excitement of new learning in near real-time. All over the Laboratory people are starting to prepare for the event . . . But the joy is tempered . . . The phrase "the end of an era" is passed around by the veterans, particularly those who have participated in the almost continuous exploration of our solar system during the last two decades. .

As Carl Sagan has said, "We are the only generation who will be the first to explore the solar system" . . . And JPL has been the heart and mind behind that exploration . . . Someday, hundreds of years from now, starry-eyed adolescents will gaze out of their schoolroom windows and envy our having been alive at this great time in the history of the human species. Our era and the exploratory zeal that fueled it will be regarded with the same wistful longing that we, in our youth, had for the great age of exploration in the 16th and 17th centuries. Instead of Columbus, da Gama, Frobisher, and Magellan, the names that will echo across their history will be Pioneer, Mariner, Viking and Voyager. . .

After the Voyager encounter with Saturn this summer, there will be a hiatus in our exploration of the solar system. . . We have grown accustomed during the last decade to a new unmanned planetary spectacular every year or two . . . a new launch, a new planet, a new set of knowledge for our children and grandchildren . . . and now it will be at least five years. . .

As for me, I plan to celebrate this Voyager encounter with all my spirit. I will raise my cup to Enceladus, the shepherding moons, and the beautiful ring system of Saturn as we show once more the ingenuity and curiosity of the human species . . . and as I raise my cup, I will celebrate all the great voyages of planetary discovery of the last decade. It has been my good fortune to share these discoveries with as fine a group of people as this planet has ever produced.

—Gentry Lee

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The Galileo Messenger

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FROM THE PROJECT MANAGER

Despite rumors to the contrary, it apparently never was the intent of the Office of Management and Budget (OMB) or the Presidential Science Advisor, Dr. George Keyworth, to cancel the Galileo Project. Dr. Keyworth explained this to me following his talk to the National Space Club in Washington, D.C. on February 24. In an article published in the *Washington Post* on December 2, 1981, Dr. Keyworth was quoted as recommending a halt to all new planetary space missions for at least the next decade. But, Dr. Keyworth explained, he never intended this statement to include halting Galileo – or the Venus Orbiting Imaging Radar (VOIR) project either, for that matter. Nor does he feel that all future planetary programs should be halted. Apparently, what Dr. Keyworth intended was that, for the next decade at least, we should suspend new starts of large, i.e., \$500 million to \$1 billion programs such as Galileo, Voyager and Viking, while continuing with smaller scaled missions in the \$200 million to \$300 million category. Dr. Keyworth is advocating a balanced program of space science missions, that is, a proper balance between planetary exploration, astrophysics, and the other fields of space science.

Further testimony to the continuing support of Galileo by the White House and the OMB is reflected by the substantial increase in funding for Galileo submitted by the President in his FY'83 budget message to Congress. This increase, of course, was a necessary consequence of switching from the NASA Centaur upper stage to the Air Force two-stage IUS (Inertial Upper Stage), which requires a third stage to be developed for use with the IUS and the use of the ΔV-EGA trajectory type.

JPL has been given responsibility for developing the new stage to be used for both Galileo and the International Solar Polar Mission (ISPM) at an estimated cost of \$50 million to be borne equally by both projects. Galileo will be the developing agent responsible for the design and implementation of the stage.

Galileo's share of the stage, plus the cost of modifying the spacecraft for the ΔV-EGA mission, the new launch vehicle integration work, and the cost increases associated with the ΔV-EGA mission, are expected to add a total of almost an additional \$170 million to the Project, bringing the total cost to \$864 million. The very fact that such a large increase in Galileo funding was supported speaks to the very strong support the project enjoys within this Administration.

– John R. Casani

ΔV-EGA MISSION

Galileo's baseline mission has changed from the 1985 launch on a direct trajectory to Jupiter to a 1985 launch on a longer trajectory that will make an initial orbit around the sun and come near Earth again before heading to Jupiter. This mission, known as ΔV-EGA, will require the addition of an injection module, lengthen the cruise phase by about two years, and decrease the number of obtainable encounters with Jupiter's Galilean satellites.

The decision to fly the ΔV-EGA mission derives from the loss of funds for the modified Centaur upper stage that was to have boosted the spacecraft out of Earth orbit and onto a direct trajectory to Jupiter. The replacement upper stage will be the Air Force's two-stage Inertial Upper Stage (IUS). However, a "kick stage" will also be needed to supply enough energy to boost the spacecraft into its initial orbit around the sun.

(The term ΔV-EGA denotes the use of a large propulsive maneuver in deep space in conjunction with a subsequent Earth gravity assist (EGA) to achieve the Jupiter trajectory.)

The scenario for the ΔV-EGA mission starts with launch in May 1985. The combined Orbiter and Probe, mated to the injection module (the "kick stage") and the two-stage IUS, will be launched to Earth orbit in the space

see page 4

MEET THE TEAM

Bill O'Neil

With a strong background in mission design and navigation, Bill O'Neil welcomed the opportunity to become involved with hardware when he became Galileo's Science and Mission Design Manager. His areas of responsibility include mission design, interfaces with the Galileo scientists, and the Orbiter's science instrument hardware.

Most of the hardware is now in fabrication, and Bill looks forward to deliveries to JPL beginning late this year. "Now its real," he says, "and this mission will be executed." Bill is also encouraged by the fact that Galileo will now have the advantage of using a fully-developed launch system, as both the space shuttle and IUS upper stage will have been fully tested and exercised by the time Galileo launches in 1985.

Bill studied aeronautical engineering, with a B.S. from Purdue and a master's degree from the University of Southern California. Since joining JPL in 1963, he has worked on the moon lander Surveyor, the Mariner Mars 1971 orbiter, and the Viking Mars landers and orbiters. He was manager of the Mission Design Section before joining Galileo.

Bill and his wife Diane live in Arcadia and have three adult children. Although they enjoy travel and downhill skiing, on many weekends Bill can be found looking after their real estate investments – painting and fixing plumbing in their "mom and pop" apartments.

RELAY RADIO HARDWARE

As the Galileo Probe enters Jupiter's atmosphere and rapidly descends through the cloud layers, its signal will be tracked by the relay radio hardware (RRH) onboard the Orbiter. This relay link is a crucial element of the Probe's mission, for otherwise there would be no way to transmit the Probe's data to Earth.

The RRH consists of a dish antenna, two receivers, and two ultra-stable oscillators. The 1.1-meter diameter antenna will be mounted on a moveable support boom attached to the non-spinning (or "despun") portion of the Orbiter. The antenna will remain in a stowed position until the Probe separates from the Orbiter about 150 days before arrival at Jupiter. After Probe separation, the antenna will be deployed. During the Probe's entry into Jupiter's atmosphere, the RRH antenna will be repointed to receive the Probe's signal. Use of this smaller, side-mounted antenna will allow the Orbiter's 5-meter antenna to remain Earth-pointed for tracking and communications.

Although the concept is simple, the Probe data relay presents special challenges that the hardware and firmware must meet. The acquisition, tracking, and transfer of Probe data to the Orbiter must occur autonomously. The receiver must automatically acquire and "lock" onto the Probe's signal within 50 seconds from the start of data transmission from the Probe. It must maintain lock for as long as the Probe survives in the increasingly hostile environment of Jupiter's atmosphere.

The first task of the Orbiter RRH will be to find the Probe's signal. It will be faint – approximately 1000 times less than the human audible level – and its frequency and signal strength will vary due to the Probe's rapid descent as well as turbulence and chemical effects in the atmosphere. During this important phase of the mission, the RRH antenna will be receiving the Probe's signal from a distance of over 200,000 kilometers, with a narrow (13°) beamwidth.

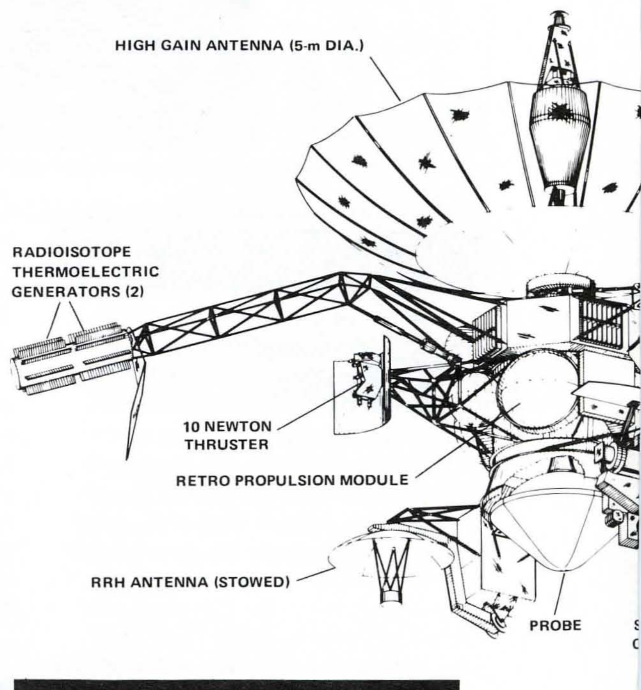
To ensure that the relay link is not jeopardized due to equipment failure, the RRH design is "redundant" – it has two receivers and two ultrastable oscillators, and the antenna is designed to simultaneously receive two channels of Probe data that are differentiated by frequency and polarization. The two receivers are physically and electrically identical except that each is tuned to its respective channel of Probe data transmission and each has a unique address for command and data transactions with the Orbiter's command and data subsystem computers. Both receive the same real-time data from the Probe. Each receiver uses an ultrastable oscillator as a reference to extract Doppler information from the Probe's signal. During the search and track modes, each receiver consumes 23 watts of power.

The RRH is controlled by a complex, permanently fixed computer sequence. Because events will occur rapidly, the Probe data acquisition, tracking, and transfer to the Orbiter must occur automatically.

The search for the Probe signal begins when power is applied to the receivers. In 16 seconds or less, the receivers will search the entire 70 kiloHertz bandwidth several times to find the Probe signal with a high probability. At the end of 40 seconds, the signal frequency and rate are estimated, and the receiver "locks" onto the signal phase within another 8 seconds. The Probe is expected to transmit for about one hour before it is silenced by the intense heat and crushing pressure.

The receiver breadboard tests and software are complete, and the qualification and flight units and unit tester are being assembled. Parts procurement is complete except for a recent change in the random access memory to provide better radiation hardness. The spacecraft will experience the most intense radiation during its close flyby of Jupiter as it relays the Probe's signal. The antenna is in the early stages of design.

Ames Research Center is providing the RRH along with the Probe system. The receivers and antenna are being developed, fabricated, and tested by Hughes Aircraft Company under contract to Ames, and the oscillators are provided by Frequency Electronics Inc. under subcontract to Hughes.



Galileo Orbi

REVIEWS

Two reviews this month represent significant milestones in the Galileo development schedule. The Final Mission and Systems Review (FMSR), to be held at JPL on May 17 - 19, is the culmination of all the Project design reviews. The agenda includes reviews of the mission design, engineering areas that comprise more than one system, and updates in several areas since the critical design reviews. In addition, the FMSR will cover all changes, both in requirements and design, resulting from the change to the ΔV-EGA trajectory.

On May 20, the On-Board Software Implementation Review (OBSIR) at JPL will assess the implementation plans of the various on-board software packages, including the attitude and articulation control subsystem (AACS), command and data subsystem (CDS), Probe firmware, and science instrument software and firmware for both the Orbiter and Probe. (Firmware is computer programming that cannot be changed after launch.) Topics to be discussed include current software status, remaining development schedule, test approach and plans, configuration management plan, software maturity, and any schedule concerns.

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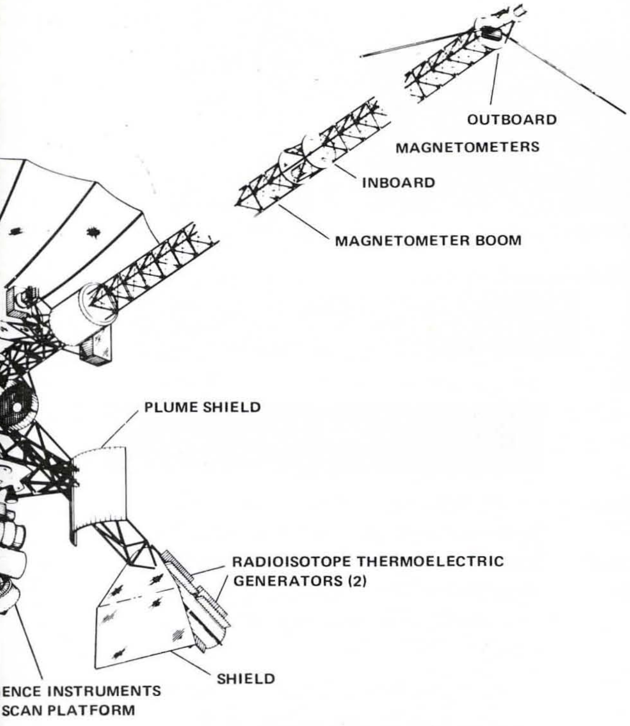


r and Probe

MAGNETOMETERS

Jupiter's magnetosphere is the largest structure in the solar system. It is millions of miles across and tens of millions of miles long. If it were visible to us, it would appear in the night sky bigger than the moon.

The magnetometer instruments onboard the Galileo Orbiter will measure magnetic fields throughout Jupiter's enormous magnetosphere, from its boundaries where interactions with the solar wind will be studied, to the inner regions where properties of the planet itself will be investigated.

Planets having large magnetic fields, including the Earth, are surrounded by magnetospheres – "bubbles" in the solar wind in which the planet's magnetic field dominates and controls the behavior of charged particles. As the solar wind streams around this area, a magnetic tail is formed on the far side of the planet. Jupiter's magnetosphere can be visualized as a giant, tattered wind sock, with a bulbous end toward the sun and an elongated, flapping tail stretched away from the sun. Most of this magnetosphere is filled with gases of charged particles.

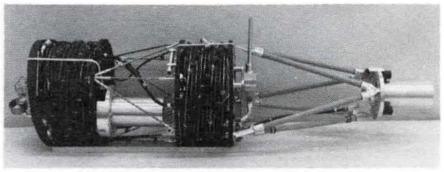
The Pioneer and Voyager missions showed that the size, shape, and internal structure of the Jovian magnetosphere changes, but they remained near Jupiter too briefly to study the process of change. As it orbits Jupiter for nearly two years, Galileo will record changes in the magnetosphere and help us understand their causes. For example, at Earth, large-scale instabilities that trigger explosive responses throughout the magnetosphere, including ionospheric effects such as aurora and radio noise, are initiated in the tail. The Galileo tour will include a large looping orbit that provides two months in the near-planetary regions of the tail where evidence of similar processes will be sought. (Jupiter's tail may extend as far as Saturn, over 650 million kilometers distant, but Galileo will go only about 11 million kilometers down the tail.)

Jupiter's four largest satellites – Io, Europa, Ganymede, and Callisto – orbit within Jupiter's magnetosphere. As the magnetized planet rotates, it sets the gases in the magnetosphere into rotation. The rotating charged particles interact with the satellites in ways that differ depending on whether or not a satellite is conducting, magnetized, or has an ionosphere. The Orbiter's tour through the Jupiter system will yield information about the magnetosphere-satellite interactions and about the satellites themselves. For example, measurements will reveal if the satellites have magnetic fields and thus provide critical information about their interiors.

Currents flowing along the magnetic field in the Jovian magnetosphere play a crucial role in coupling the magnetosphere with the upper atmosphere. In recent years such currents have been measured at Earth, but their importance at Jupiter was recognized much earlier. These currents stimulate radio emissions from the ionosphere (both at Jupiter and at Earth) and may play a role in producing auroras much like Earth's Northern and Southern Lights. Neutral atoms coming from Io or other moons are "spun up" to the rotation rate of the surrounding charged particles by forces transmitted from the ionosphere along the magnetic field of the magnetosphere. Exchange of mass and energy between the planet and its magnetosphere may occur along these field lines.

During the long journey to Jupiter, the magnetometer instrument will study the properties of interplanetary fields, including fast streams and interplanetary shocks. Long-term measurements of the solar wind magnetic field at great distances from the sun will be studied to find changes as solar activity increases in the next solar cycle.

The instrument consists of six sensing circuits, data handling circuits, and power circuits. Two clusters of three sensors each are mounted on an 11-meter boom which unfurls from the spinning section of the Orbiter after IUS separation. One set of sensors is mounted at the tip of the boom, while the other is about 6.7 meters from the spacecraft spin axis. The sensors must be placed at some distance from the main body of the spacecraft to minimize magnetic effects from the spacecraft. On the spacecraft, the sensed magnetic field is converted from an analog voltage to a digital signal. Data indicating the orientation of the spacecraft is added and the measurements are analyzed by the instrument's data processor. Effects caused by spacecraft-generated fields or the electronics circuits can be identified, measured, and separated during the data analysis so that only physically useful data need be transmitted to Earth. The challenge associated with pushing the on-board data processing capability of the instrument to its limit has been met successfully in the magnetometer design.

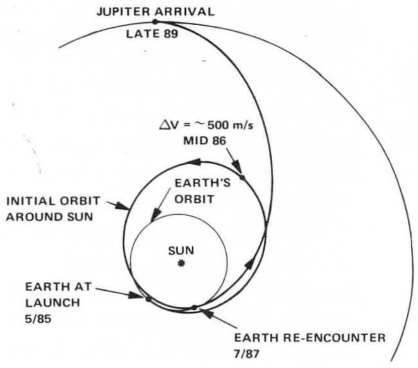


Magnetometer Sensors and Collapsed Boom

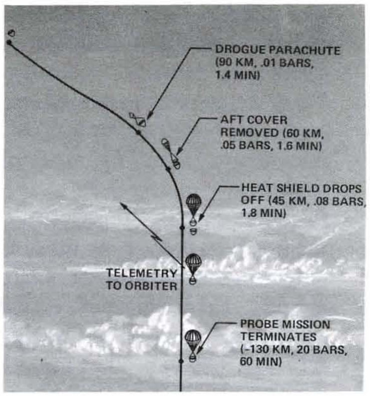
The basic magnetic measuring device, the ring-core sensor, was fabricated by the Naval Surface Weapons Center, White Oak, Silver Spring, MD. The entire assembly and associated electronics were designed by the University of California, Los Angeles, and fabricated by the Westinghouse Electric Company. An RCA microprocessor is used. The instrument is now at UCLA where it is undergoing tests and calibration.

The principal investigator for the magnetometer experiment is Dr. Margaret Kivelson, professor of space physics in the earth and space sciences department at UCLA. She is supported by four co-investigators from UCLA.

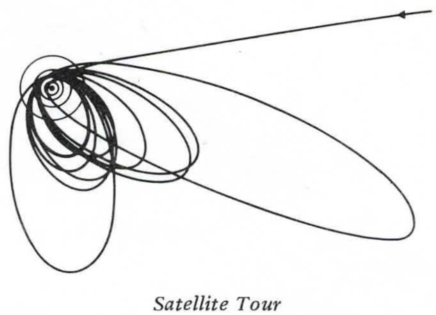
Dr. Margaret Kivelson



ΔV-EGA Mission Plan



Probe Descent



Satellite Tour

from page 1

shuttle's payload bay. The shuttle will release the spacecraft and return to Earth. Soon after release from the shuttle, the IUS and injection module engines will fire, sending the spacecraft into an orbit around the sun that will bring it near the Earth again slightly more than two years later, in the summer of 1987. In mid-1986 a large propulsive maneuver of about 500 meters per second will shape the trajectory to obtain the near-Earth geometry required for the Earth gravity assist to Jupiter. The Earth flyby will be at an altitude of about 225 kilometers.

The spacecraft will cruise another two-and-a-half years to Jupiter, arriving in late 1989. Some fields and particles measurements will be made during the Earth-to-Earth and Earth-to-Jupiter cruise phases.

About 150 days before Jupiter encounter, the Probe will separate from the Orbiter and continue its path toward the planet. About three days after Probe release, the Orbiter's flight path will be adjusted to assure that it will be overhead to receive the Probe's radio signal as the module enters Jupiter's atmosphere and sinks through the clouds.

Once the Orbiter and Probe are separated, the Probe will be on its own. It cannot receive commands. Its instructions are pre-programmed into its computer memories, and its entry sequence starts on a timed command. The Probe will hit the atmosphere at a little over 47 kilometers per second – the fastest entry yet attempted in any space mission. After entry, the Probe's protective aeroshell will be jettisoned, and the Probe will descend on a parachute.

During the descent, which may last as long as one hour before the Probe perishes, six different science instruments will take data that characterize the atmosphere of Jupiter. This data will be transmitted to the Orbiter overhead, and the Orbiter will then send the data to Earth.

About four hours before the Probe's mission begins, the Orbiter will fly past the volcanic satellite Io at an altitude of about 500 kilometers. This will be Galileo's only close Io encounter, due to the intense radiation near Jupiter. Repeated exposure to this radiation would damage the spacecraft.

About 30 minutes after the end of the Probe mission, the Orbiter will fire its retro propulsion engines to slow itself and be captured by Jupiter's gravity. The initial orbit of Jupiter will take about 250 days. Midway through this orbit, the engines will fire again to raise perijove altitude (the closest approach distance to Jupiter) to protect the spacecraft from radiation near the planet.

For the next 24 months, the Orbiter will make a series of looping orbits around Jupiter, providing at least one close satellite encounter on each orbit to study the other three Galilean satellites – Europa, Ganymede, and Callisto. Currently, the estimated number of satellite encounters ranges from seven to ten, depending primarily on the date of launch. The Orbiter will also characterize Jupiter's magnetosphere, make long-term studies of the dynamics of the planet's atmosphere, and investigate Jupiter's tenuous ring.

NASA

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

POTPOURRI

We have another new mission and a new upper stage. . . .fortunately the launch date is still 1985 and the project appears stable. . . .maybe this will be our last significant programmatic change.

With the demise of all the rest of the planetary programs, Galileo is now the sole surviving descendant of the Mariner, Viking, Voyager line. . . .we carry the tradition and the responsibility. . . .as a result, the pressure on us is perhaps greater than if we were one of many. . . . we must make Galileo a success.

Changes, changes. . . .three planetary old hands have gone or will go to other positions. . . .in addition to Dr. Murray, Tom Young, who was mission director on Viking, has left NASA to join a private firm. . . .and Andy Stofan, past deputy administrator of the Office of Space Science, has left Headquarters. . . Andy fought some valiant battles for Galileo.

Cosmic rays are made when giant stars die in a supernova blast. . .they travel across the universe and affect us here on earth, not only by causing mutations but also by causing sophisticated electronic parts to "upset". . .in layman's terms, a binary "0" may become a "1" because of a charge deposited in the semiconductor by a cosmic ray. . . we have been studying this problem for Galileo, trying to figure out how to handle it. . .in quiet moments I muse about the beauty of knowledge and the universe and this exploration profession. . .we humans must understand the output from the death throes of an earlier star in order to design miniature computers to help us explore our solar system. . .this is one facet of a richly rewarding job, to see the delicate interrelationships among all parts of the cosmos.

–Gentry Lee

The Galileo Messenger

1625-101, ISSUE 4 AUGUST 1982

FROM THE PROJECT MANAGER

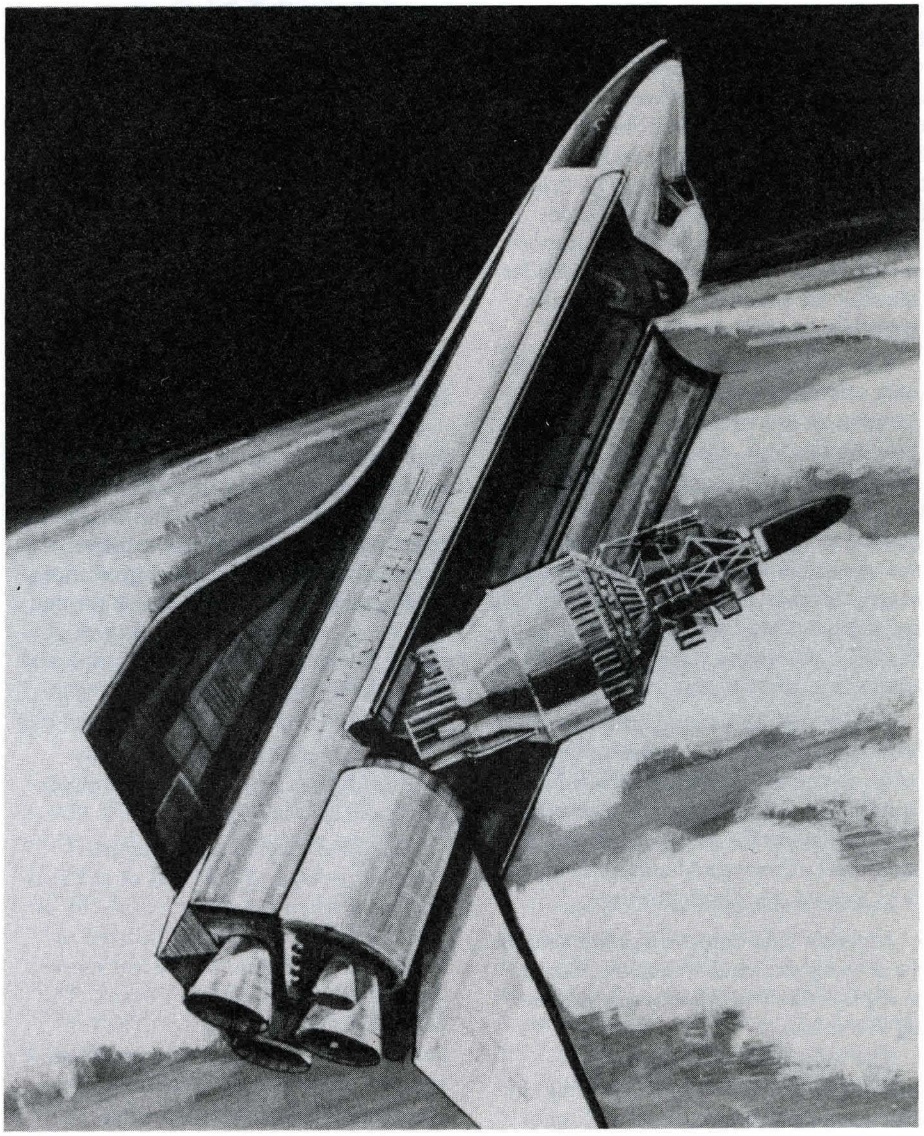
On July 20, John Casani called an "all-hands" meeting of the Galileo team at JPL to announce the latest reprogramming developments. As of now, "stop work" orders have been placed on all injection module subcontract activity, and phase-down of the in-house activity will be complete by the end of this fiscal year. Work has begun on re-integrating the Centaur stage for an '86 launch. A condensed version of the talk is given below.

On July 18, President Reagan signed a supplemental appropriations bill which directs NASA to develop the wide-body Centaur as a Shuttle upper stage and to launch Galileo with it in 1986. I'd like first of all to give you the background that has brought us to this point and then describe where we go from here.

At the Project's inception in 1977, Galileo was scheduled to be launched in January 1982 aboard the Space Shuttle using the NASA three-stage version of the Inertial Upper Stage (IUS). Due to Shuttle development and schedule problems, Galileo was redirected, in 1979, to a 1984 split launch, with the Orbiter and Probe launching about a month apart. The split launch was required because the increased launch energy requirements could not be satisfied with a single Shuttle/IUS launch in 1984.

In 1981, NASA dropped development of the three-stage IUS due to escalating costs and adopted the Centaur as the high-energy upper stage. The launch schedule was slipped to 1985 to allow time for the necessary development and integration effort. However, the improved upper stage performance allowed the Orbiter and Probe to be recombined for a single direct launch.

Funding for the Centaur was in the budget for fiscal year 1982 (FY82) sent by the Administration to Congress. However, in December 1981, due to federal budget problems, the Centaur was deleted from the FY83 budget. At this point, a revised FY82 operating plan, dropping Centaur funding and adding funds for a planetary version of the USAF two-stage IUS and the Injection Module, was sent to Congress. Although no specific approval for the revised operating plan was given, the Administration directed that work on the Injection Module, the planetary two-stage IUS, and the Galileo ΔV-EGA mission begin.



Shuttle, Centaur, and Galileo

The ΔV-EGA mission would have launched in May 1985, about one month later than the '85 Centaur mission. It would have required a single launch of a combined Orbiter and Probe, a two-year orbit around the Sun with a large propulsive maneuver about one year out, and an Earth reencounter. Earth gravity assist would then boost the spacecraft on to Jupiter with arrival in late 1989. The large propulsive maneuver would have depleted much of the Galileo propellant, causing a major redesign and greatly reduced margins for the Orbiter's tour of the Galilean satellites.

In recent months, Congress has been working on the so-called FY82 Urgent Supplemental Appropriations Bill to provide funding for various agencies that otherwise could not operate through the remainder of the year.

A provision of the bill directs NASA to restart development of the Centaur for launching Galileo and the International Solar Polar Mission in 1986. The language states that no more funds are to be obligated for any other upper

see page 4

PROBE MASS SPECTROMETER

A mass spectrometer in the Galileo Probe will directly and repeatedly sample Jupiter's atmospheric gases at different altitudes at the Probe descends.

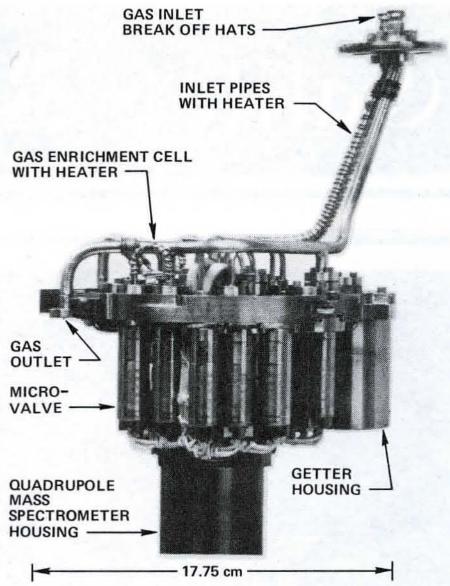
Remote sensing instruments flown on four previous Jupiter flyby missions have provided valuable information on wind patterns and physical composition in the planet's upper atmosphere, but they have only "scratched the surface". Such instruments cannot precisely study the vertical mixing of gases. The Probe's mass spectrometer will provide a detailed analysis of the chemical composition of the atmosphere and aid in understanding the processes resulting in the complex, colorful clouds.

The Jovian atmosphere is star-like – some scientists believe its elemental abundances are virtually identical with those on the Sun. Comprised primarily of 90 percent hydrogen and 10 percent helium, it also includes minor amounts of the inert gases neon, argon, krypton, and xenon, and non-inert gases such as water, methane (CH_4), ammonia (NH_3), hydrogen sulfide (H_2S), acetylene (C_2H_2), and ethane (C_2H_6) as well as other trace constituents.

Unlike remote sensing instruments, Probe instruments can make measurements in the lower atmosphere, where clouds form. The Probe is expected to pass through at least two cloud layers composed of water and ammonia during its projected 60-minute lifetime.

Jupiter's wild colors originate deep in the atmosphere, and it may be possible to explore the role of sulfur in generating the colors.

The mass spectrometry measurements will also aid in understanding the processes involved in the formation of the solar system. The noble gases – helium, argon, krypton, and xenon – are chemically inert; that is, they do not combine with other elements to form other compounds. They do not settle out of a planetary atmosphere by liquifying or freezing, but remain in the gaseous state. Therefore, there should be the same abundances of them now as there was at the beginning of the solar system. Cosmic abundances of krypton and xenon are poorly defined, so the Probe's mass spectrometry offers the first opportunity to measure these elements in a single undisturbed reservoir. The results can be used to calibrate a very large mass of data on noble gas abundances in meteorites, the Earth,



Gas Inlet Housing Structure

and the inner planets.

Voyager's discovery of lightning on Jupiter raises anew the possibility that organic compounds (the basis of life on Earth) may be formed in the Jovian troposphere. A classic laboratory experiment several decades ago showed that organic compounds can be formed when a spark is struck in a mixture of gases. Galileo will search for samples of organic compounds such as hydrogen cyanide and acetonitrile.

Abundances of photochemically-produced gases and other trace constituents will also be evaluated.

The mass spectrometer identifies gases by measuring the mass of the ions produced when the gas is ionized by an electron beam. As gas is admitted to the ionization region of the ion source, it is ionized by an electron beam. The beam energy can be varied. The ion beam is then directed into a quadrupole analyzer, a set of four hyperbolically-shaped rods 15 centimeters long. A radio frequency voltage is applied to the rods to filter the incoming ions. The voltage and frequency can be varied so that only ions of a chosen mass and charge can travel the length of the rods and be counted at the ion detector.

Atmospheric gases will enter the mass spectrometer through two inlet ports at the apex of the Probe. These ports will be sealed by metal-ceramic devices and kept under vacuum until the Probe enters the Jovian atmosphere. Pyrotechnic devices will then release the covers, allowing atmospheric gases to enter and be pumped to the test cells.

With its broad mass and sensitivity range, the instrument measures almost everything that enters it, making it ideal for this exploratory mission. The normal range of ion masses to be covered will be from 1 to 52 AMU (atomic mass units) with occasional sweeps from 1 to 150 AMU to search for heavier compounds.

A small fraction of the gas goes directly to the ionization region where the composition of the total sample is measured. One task of the spectrometer will be to separate the hydrogen from the gas samples to raise the relative abundances of the remaining gases in the sample. The instrument includes two "enrichment" cells and one "purification" cell. Some gas passes through the enrichment cell where substances called getters adsorb trace gases such as hydrogen sulfide, phosphine, and complex hydrocarbons until only the noble (inert) gases remain. The noble gases are admitted to the ion source for analysis. The enrichment cell is then heated, the adsorbed gases are desorbed, and the gases are admitted to the ionization region for analysis of the more complex compounds.

Galileo's mass spectrometer is a "state-of-the-art" instrument. Particularly difficult problems and choices in designing the instrument relate to the "plumbing": the inlet lines, gas handling, pressure reducing, and pumping systems. A special problem was designing a pumping system that could efficiently remove one of the major components, helium (which is typically difficult to "pump"), without contaminating the spectrometer from the pumping system itself.

The instrument is being built at Goddard Space Flight Center. The engineering unit will be delivered August 1, 1982 and the flight unit is in fabrication now. The instrument weighs 11.8 kilograms and consumes about 25 watts, about half of which is consumed in pumps and heaters in the pumping systems.

Dr. Hasso B. Niemann of NASA's Goddard Space Flight Center, Greenbelt, Maryland, heads a team of seven other investigators.

Dr. Hasso B. Niemann

GREAT BALLOON DROP

A major milestone was reached on July 17 with the successful balloon drop of a test model of the Galileo Probe. The following is condensed from an article by Don Kindt, Galileo's Probe Spacecraft System Integration Manager at JPL.

The Galileo Probe is designed to be carried to Jupiter by the Galileo Orbiter and then released to enter the Jovian atmosphere on its own. After a fiery, red-hot entry, the Probe will shed its protective heatshield and descend by parachute through the atmosphere of Jupiter, sending data back to the Orbiter until the heat and pressure of the Jovian atmosphere destroy the descent module.

How can the Probe be tested here at Earth to make sure that it will work at Jupiter? The only practical way is to lift a test Probe high above the Earth by balloon and drop it. So, on July 17, a test model of the Galileo Probe was dropped at White Sands Missile Range, New Mexico, to test the Probe's separation mechanisms and parachutes.

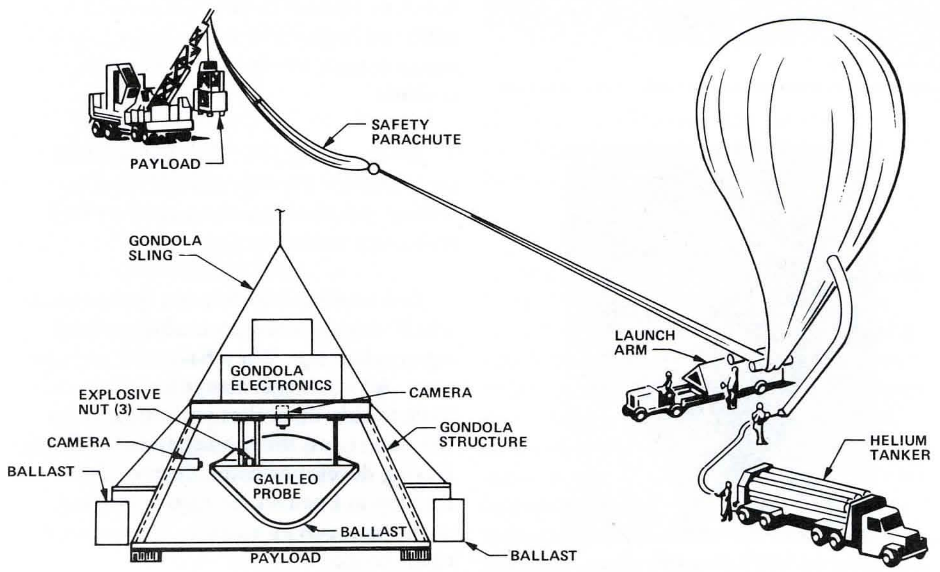
Months of preparation were required to bring together all the test equipment. The test Probe was built by General Electric Co., subcontractor to Hughes Aircraft Co., the prime contractor to the Probe developer, NASA's Ames Research Center. The balloon was provided by the Air Force Geophysical Laboratory, and final tracking and recovery was coordinated at Holloman Air Force Base.

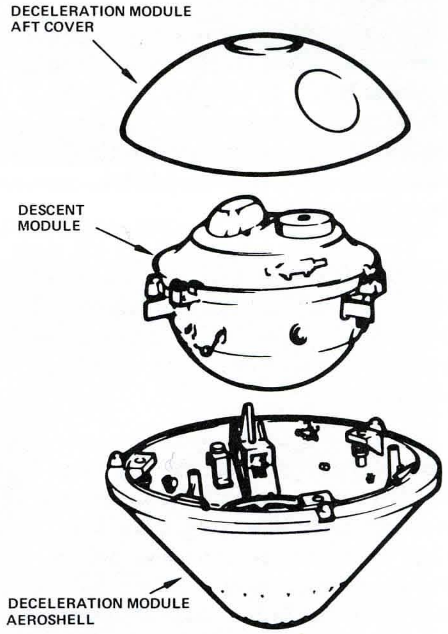
Wind conditions were monitored carefully until the right conditions existed for the test. Not only did the winds have to blow from east to west at these altitudes, but they had to blow fast enough to carry the balloon over White Sands before the batteries ran out onboard the Probe and the supporting Air Force gondola. The drop also had to occur in daylight so the events could be recorded on film. *(Ed. note: Photographs were not available at press time.)*

The Probe was held in the Air Force gondola, which is like an upside down basket. The gondola provided pre-drop power, heating, movie cameras, and other balloon-related equipment. The gondola (with its Probe cargo) was rolled out of the hangar, hoisted on a portable test crane for weighing, and then transferred to the huge portable launch crane to hang suspended above the ground until the moment of launch.

Meanwhile, the 400-foot-long polyethylene balloon was carefully unpacked from its six-foot-square container and stretched out along the deserted runway at Roswell, N.M. Inflation with helium began about one hour before launch, until the 5.14 million cubic foot balloon expanded, rose, and tugged at its tether. (After launch, at 100,000 feet (19 miles) altitude, its diameter expanded to about 234 feet.)

As the launch command was given shortly after dawn, a minor hitch in the release mechanism required a sledge hammer. The problem solved, the payload crane truck (with its dangling payload) was driven in the direction of the wind until the truck was directly under the rising balloon and the payload was towed skyward by the rapidly ascending balloon.





Five hours after launch, carried about 120 miles west by winds up to 36 knots, the Probe was released. It freefell to an altitude of 57,300 feet, where the pilot chute deployed (its speed was .998 Mach). At 55,600 feet, the main chute deployed and the aft cover released, and at 53,900 feet, the heatshield separated from the descent module. Moments apart, the pilot chute and aft cover smashed to the ground at 62 feet per second, the heatshield at 109 feet per second, and the main chute and Probe descent module at 56 feet per second.

The balloon was destroyed by command several minutes after Probe release, and the gondola drifted to the desert floor on its recovery parachute. A crew was sent to pick up the parts of the Probe and to recover the gondola for future use on other Air Force jobs.

All the data and pictures will have to be analyzed to confirm that everything worked according to design. If so, the next stop is Jupiter!

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Pasadena, California

from page 1

stages, and only current obligations and termination costs are allowable. It also requires NASA to advance the operational readiness state of the second Shuttle launch pad to January 1986 to allow both the Galileo and ISPM launches in 1986.

The first two versions of this bill were vetoed by the President. He signed the third version of the bill into law on July 18, 1982, and NASA has begun the process of implementing the Centaur provision.

Why in the face of so many objections, did Congress reinstate the Centaur? There are several reasons *as I see it*. First, there is high regard within Congress for the achievements of the Planetary Program, and concern by many that the future of the Program would be severely eroded if constrained to the existing launch vehicle capability. Second, the Air Force will require a higher energy stage in a few years and Congress was reluctant to abandon the 20 years of development investment, proven reliability, and maturity in exchange for a major new development program with a new round of development cost risks. Third, Congress wanted NASA to have responsibility for the upper stage development and this might not have happened if a new high energy upper stage development with heavy Air Force requirements was started. Lastly, and perhaps most significantly, Congress is concerned about the exodus of commercial customers to the European Ariane launch vehicle. Arianespace's stated objective is to capture 30 percent of the commercial market through 1985 – already they have booked nearly that amount. The Centaur's recurring costs have been stated as about half those of the IUS with twice the launch capability, which has led some to believe that with the Centaur it would be possible to keep or recapture more of the commercial market.

As for Galileo, we must stay on our present development and test schedules for both the Orbiter and Probe.

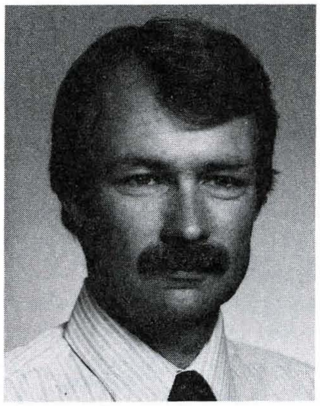
To control the cost and maintain the stability of the ongoing activities, it is mandatory that absolutely no changes be made to the spacecraft; i.e., to any hardware on the spacecraft side of the IM/spacecraft adapter interface. All necessary interface accommodations will be confined to an assembly consisting of a new intermediate adapter which should "look like" the IM at the forward end and "like" the old Centaur '85 spacecraft adapter at the other end.

As for the Injection Module, that work must stop.

I want to personally thank, on behalf of the Project and the Laboratory, Joe Savino and each of the people working on the Injection Module Team for the fine job they did in the past six months. It has been a truly remarkable effort. An incredible amount of quality work has been accomplished, with everything clicking off right on schedule. It is keenly disappointing to be doing a job well, with intensity and dedication, only to have it terminated so abruptly for reasons totally beyond your control. Nonetheless, we must bring this work to an orderly close now, and get to work reintegrating with the Centaur and with reprogramming to the 1986 mission.

The Injection Module and ΔV-EGA mission design work was important because it demonstrated our resourcefulness, our ingenuity, and our adaptivity to rapidly changing circumstances. We must reach for those same qualities again as we begin the process of adapting to the '86 launch. We must always remember that our ultimate objective is to deliver a fully functional Galileo spacecraft – Orbiter and Probe – to Jupiter. With the reinstatement of the Centaur we can achieve that goal in 1988, one year earlier than we could have with the ΔV-EGA mission, even though the launch is one year later. The Centaur will not only get us there faster, but with more propellant in our tanks, which means higher assurance of obtaining our science and mission objectives.

All in all, the change is good. The promise Galileo holds is greater than ever and, with your continued support and enthusiasm, the payoff will be there.



Bob Mitchell

MEET THE TEAM

Getting from here to there is the daily business of Galileo's Mission Design Manager, Bob Mitchell. The simplest task of his day is walking to JPL from his home in La Canada-Flintridge. After that, things get more complicated.

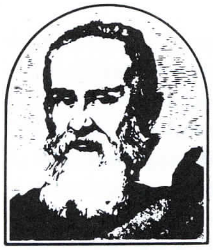
"Mission design is the process of generating trajectories (flight paths) and plans for implementing a mission within the constraints imposed by the Project and the laws of celestial mechanics," explains Bob. "There are certain kinds of trajectories and tours that best meet the mission objectives, and we have varying degrees of flexibility in designing these trajectories. It becomes a matter of determining options and tradeoffs."

Each time the Project has undergone reprogramming by NASA, Bob and his co-workers in JPL's Mission Design Section have generated a new mission design, identifying the best route to Jupiter and the orbital tour that will return the most science data. Besides the official baseline missions, they have studied other options. Trajectory choices are complicated by matters such as launch vehicle performance, spacecraft propellant utilization, solar conjunctions, occultations, ring plane crossings, Probe entry speeds, aspect angles, and numerous other requirements levied by the navigation and science teams.

Bob holds an undergraduate degree in electrical engineering, and graduate degrees from the University of Arkansas in electrical engineering and mathematics. Were it not that a spur-of-the-moment resume to JPL produced a job offer, he might now be designing automatic control systems for Caterpillar tractors.

Since joining JPL, Bob has worked on Mariners '67, '69, and '71, and on Viking, primarily in the maneuver and trajectory areas.

Bob and his wife Vineda (pronounced Vin ē′ da) are active in challenge level square dancing. They have two teenage sons and a younger daughter. Bob also likes to ride dirt bikes with his sons in the desert and the mountains of Mexico. Having developed some degree of fluency in Spanish, he enjoys visiting with the locals as much as finding new roads to explore.



The Galileo Messenger

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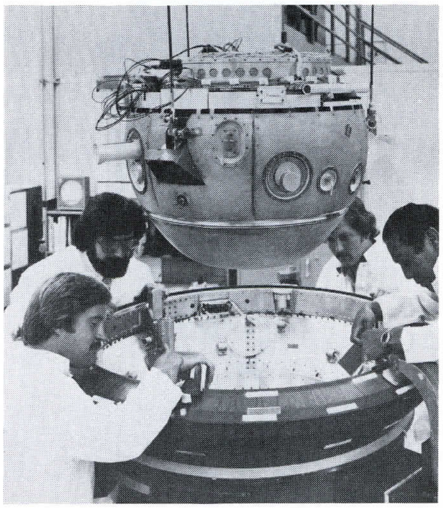
From the Project Manager

We are entering a critical stage in the life of any mission – integration and test. Now comes the "proof of the pudding" – whether all subsystems will fit together and play together as planned and designed.

The Galileo Probe is already undergoing system tests, and has been in integration testing since last spring. Environmental testing – thermal vacuum, vibration, pyro shock, descent pressure and temperature, and entry deceleration (high-g) tests – will begin at Hughes Aircraft Company in January 1983. Problems with the data and command processor have delayed the start of environmental testing by two months, but Hughes still expects to be able to deliver the Probe to JPL in October 1983 for integration with the Orbiter.

Orbiter system test and integration is scheduled to start in February at JPL's Spacecraft Assembly Facility (SAF). Some of you already may have had an opportunity to view the high-gain antenna assemblies from the high-bay viewing gallery as they undergo testing. Dr. Lew Allen, JPL's new director, was part of a group on-hand to view the deployment test of the flight antenna on October 15.

The Galileo Orbiter is the most complicated of any JPL system yet devised. The need to fit within the Shuttle's cargo bay necessitated the furlable antenna and the folding booms for the radioisotope thermoelectric generators and some of the science instruments. The need to provide a steady platform for the optical instruments yet still allow the fields and particles instruments to sweep the entire sky necessitated the dual-spin design. To assure reliable electrical interfacing across the spun-despun section, a hybrid approach was devised, using slip rings for power and grounding and rotary transformers for high rate data signals.



Engineers at Hughes Aircraft integrate the Probe descent module with the deceleration module aeroshell in preparation for last summer's drop test.

Concern about prolonged exposure to the Jovian environment necessitates extra spot shielding, improved techniques for radiation hardening of parts, and circuit and shielding design to decrease the possibility of electrostatic discharges. Radio science data will be increased by the addition of an X-band uplink capability provided by an X/S-band downconverter receiver.

These are only a few of the engineering challenges to be met in the design, fabrication, and integration of the spacecraft. The highly skilled and specialized engineers who participate in the SAF activities will become the team that operates the spacecraft after launch and throughout its flight.

Support equipment deliveries to SAF will begin on December 15, 1982, while flight deliveries are scheduled for February 1983. Now comes the arduous task of putting it all together – the hardware, software, and operations – to permit early resolution of system incompatibilities.

– *John Casani*

Meet the Team

Asked to describe Galileo's Flight Systems Integration Manager, one staff member grinned and said, "He's a Polish mechanical engineer who drives a Corvair he spent a year rebuilding."

Dick Spehalski, also known as Spe, says he's been at JPL "all my life" but he actually came here directly from Cornell in 1959. Spe is responsible for the mechanical engineering aspects of the Galileo Orbiter; integration with the major external interfaces including the Shuttle, Centaur, Department of Energy (RTGs), Federal Republic of Germany (RPM), and the Probe; and Orbiter and Spacecraft system test and launch operations.

"Moving from the expendable launch vehicles to the Shuttle has brought a new set of complex interfaces and exacting safety requirements," Spe notes. "Integration with the external interfaces has presented a demanding set of tasks. Frequent reprogrammings have kept our own designs and interfaces in a state of upheaval, but meeting the challenges has been interesting and rewarding."

Prior to joining Galileo in 1977, Spe was the Applied Mechanics Division Representative to the Voyager Project

see Page 4

Dick Spehalski

S- and X-Band Antenna

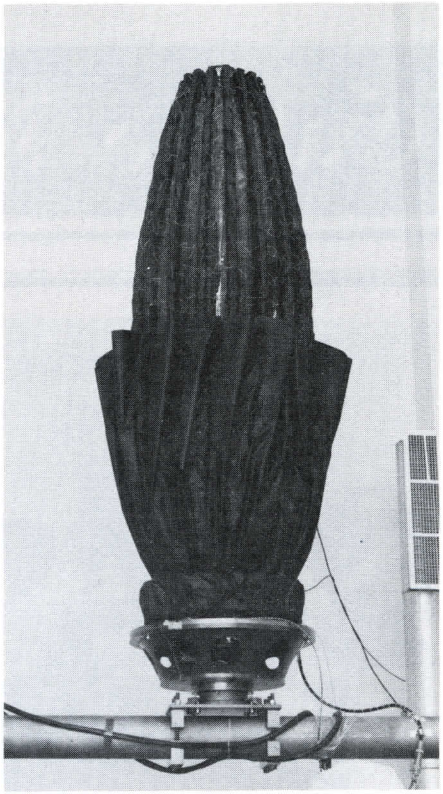
The protoflight and flight units of Galileo's main antenna arrived at JPL in late summer for test and integration. Lou Keeler, technical manager for the antenna system, provided the following summary of its design.

The communications antenna aboard the Galileo Orbiter is a 4.8-meter diameter space-deployable rib and mesh structure. In order to fit in the Space Shuttle's cargo bay, the antenna must be furled during the launch phase. After deployment from the Shuttle, the antenna will unfurl to be nearly 16 feet in diameter; it weighs only slightly more than 76 pounds.

The antenna was designed and developed by the Government Electronic Systems Division of Harris Corporation in Melbourne, Florida, and is designed for S- and X-band frequencies. The predicted gain is 50.1 decibels (dB) at 8418 MHz and 37.6 dB at 2295 MHz, while half-power beamwidths are approximately 0.45 degrees and 1.8 degrees at 8418 MHz and 2295 MHz, respectively.

Testing is now beginning at JPL with radio frequency performance and vibration, acoustic, and thermal/vacuum environmental testing. The antenna is a modified version of that developed for the Tracking and Data Relay Satellites (TDRS), the first of which will be launched on the Shuttle next year.

The Galileo antenna uses 18 rigid graphite fiber-reinforced epoxy ribs to shape and support the reflective mesh surface. The reflector mesh is made of a fine-drawn (1.2 mil diameter), gold-plated molybdenum wire which is knit* into an elastic fabric capable of being folded for the launch configuration and unfolded in orbit while maintaining precise surface contour geometry. The high-accuracy surface contour is achieved through the use of a secondary drawing surface-shaping technique. A series of circumferential multi-strand quartz cords is attached to the rear side of the ribs by adjustable standoff devices, while a second series of circumferential quartz cords runs parallel to the front cords and is attached to the



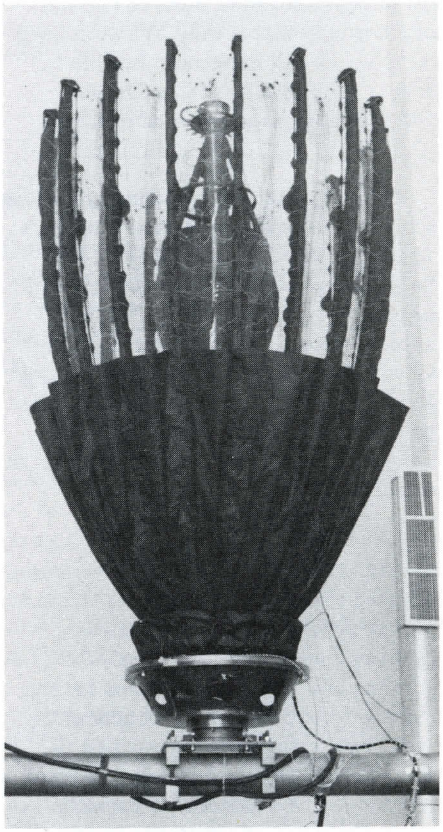
front mesh surface. Fixed-length stainless steel tie wires connect the front and rear cord systems and shape the mesh paraboloid in the circumferential directions. Through a series of rib rotation adjustments, standoff height adjustments, and rear cord length adjustments, the desired shaped paraboloid contour is achieved, with approximately 0.020 inch root mean square (RMS) contour roughness. Small black spots on the mesh are targets for theodolite (surveyor's angles) measurements that are fed into a computer when the surface shape is being adjusted.

The 18 rigid ribs are folded and preloaded around the central feed support tower during the launch phase of the mission. Deployment begins with the energizing of redundant non-explosive initiators which release a central release mechanism, freeing the rib mid-points from their stowed and locked configuration. At this point, a mechanical drive unit begins rotating a ballscrew assembly, causing a ballnut and carrier assembly to begin translating along the antenna boresight axis. As the carrier translates, 18 spring-loaded pushrods begin rotating the ribs outward. Once the ribs have hit pre-set mechanical stops, the drive unit continues raising the carrier assembly, the pushrod springs compress, and an over-center condition is reached with the ribs positively preloaded against their stops and the mesh surface properly tensioned. The mechanical drive unit for this antenna, called the Dual Drive Assembly, was designed and built by JPL design personnel and features fully-redundant brushless DC-type motors driving redundant harmonic gear passes.

Both S- and X-band feed systems are supported from the reflector structure by a six-strut truss system made of lightweight beryllium tubes which allow adjustability in order to align the feeds with the final reflector surface geometry.

The X-band system uses a frequency selective subreflector in a Cassegrain configuration. The S-band system is a focal-point feed reflector system. The frequency selective surface passes S-band energy and reflects X-band energy. This allows the S-band focal-point feed to be located behind the X-band Cassegrain subreflector. The subreflector was specially shaped to optimize X-band performance.

The S- and X-band energy is transmitted through a dual-skin quartz and



Above left and above: The Galileo flight antenna unfurls during the deployment test on October 15. Right: Antenna cognizant engineer Mark Gatti serves as a human yardstick for the fully deployed protoflight antenna. The identical antennas are currently undergoing radio frequency performance and environmental testing at JPL.

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*Ed. note: On a machine that usually knits nylon hosiery.

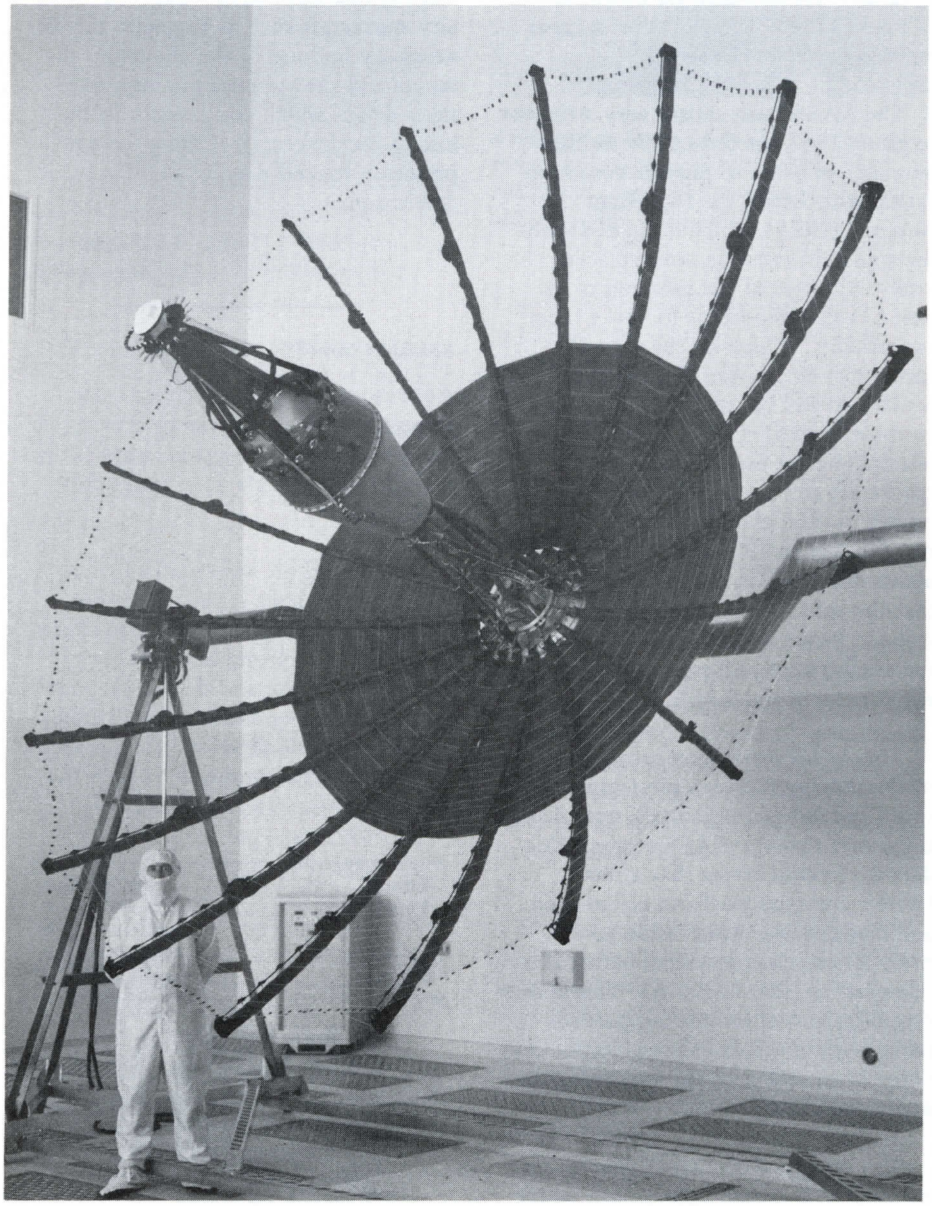
Nomex honeycomb radome structure. A thin shell beryllium structure atop the radome houses the rib central release mechanism and supports a Kevlar tower on which is installed a low gain antenna and components of the Galileo Plasma Wave Subsystem experiment. The ribs and the central tower are covered by a black material that serves as part of the thermal blankets or as a conductive surface to remove electric charges.

Potpourri

Two major Galileo reviews – the design of the fault protection system and the plans for design verification and system test – occupied a full week of the November calendar. The broad scope of the reviews forced an extremely valuable system integration process, and an enormous amount of information was exchanged.

Many of us rejoiced when the reviews were completed, but not solely for the quality of the reviews. We celebrated because the climate has changed on the Project. As we near the start of system testing, the business of engineering now dominates our discussions. After years of delays and reprogramming replete with anxieties about the very survival of Galileo, it is now clear that we have a project. The job we must do now is the one we all know best – build the highest quality spacecraft possible within the cost and schedule constraints, and send it to Jupiter to gather for all mankind the secrets of the giant planet and its fascinating moons.

– Gentry Lee



Attitude and Articulation Control

The dual-spin Galileo is a challenging departure from the traditional three-axis stabilized and all-spin spacecraft which have plied the solar system in the past. The configuration combines attributes of both types of vehicle: an inertially stable platform for precisely aiming optical instruments, and the sky-sweeping continuous rotation desirable for fields and particles experiments.

Though gyroscopic stability is a favorable aspect of this system, the dual-spinner poses a unique set of control problems by introducing the complexities of rotational dynamics into the critical pointing control considerations which occur in the three-axis design. Combine these factors with the need for advanced flight software capable of providing autonomous operation and onboard attitude determination, and it is apparent that the Galileo Attitude and Articulation Control Subsystem (AACS) represents the most sophisticated state-of-the-art application of control system technology.

The AACS consists of many individual components, all governed by the Attitude Control Electronics (ACE), the heart of which is an ATAC-16MS 16 bit/word microprocessor. The ACE communicates with the Command and Data Subsystem (CDS) via the spacecraft CDS bus, receiving commands and transmitting telemetry as required. The ACE also controls the Retro Propulsion Module (RPM) via the Propulsion Drive Electronics (PDE) which contain the logic and drive electronics for the thruster valves and latching isolation valves.

The AACS utilizes a Star Scanner (SS) mounted to the spinning part of the spacecraft as its primary source of attitude control data. A photomultiplier tube senses star crossings through a V-slit aperture and lens system, providing information which is processed by the AACS software and compared against an onboard star catalog. This is the basis for Galileo attitude determination relative to an inertial coordinate system. Galileo has adopted the Earth Mean Equator of 1950 (EME-50) as its standard reference frame. Command and control of Galileo is facilitated entirely by the AACS through this reference system.

AACS (contd)

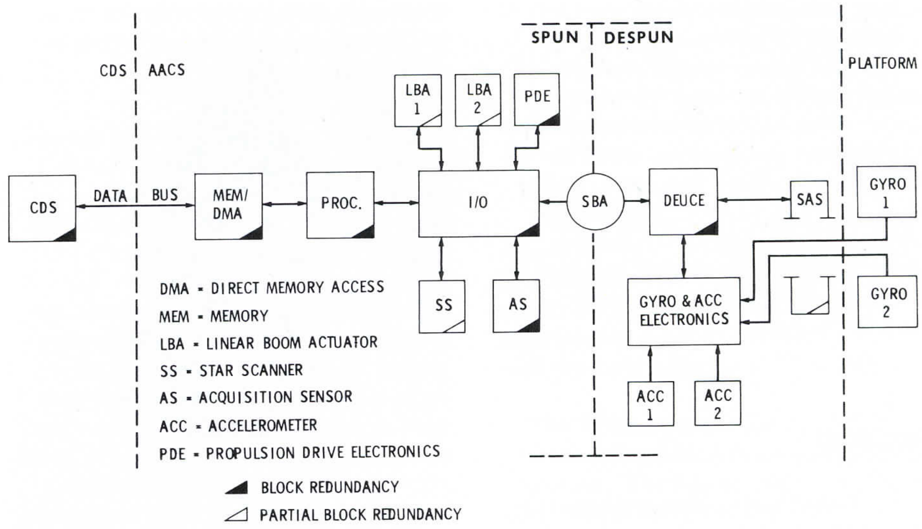
A set of gyroscopes is attached to the scan platform to provide three-axis inertial reference for the platform. This allows the scan platform to compensate for spacecraft motion. Gyro data is also used for spacecraft orientation during periods when the star scanner is not usable as, for example, during maneuvers.

Acquisition sun sensors on the spinning section sweep the sky and generate back-up spin rate and sun direction information. This provides a simple method by which a sun-pointed orientation can be achieved from any random attitude. This is important for attitude recovery in the event of a failure.

Two accelerometers measure spacecraft velocity changes along the spin axis. This is used to control the magnitude of trajectory correction maneuvers as well as for compensation for non-gravitational forces which affect navigational accuracy. Galileo can also perform lateral velocity changes by timed thruster burns.

The Spin Bearing Assembly (SBA) couples the spinning and non-spinning parts of the Orbiter, referred to as the rotor and the stator, respectively. A brushless DC motor provides the torque necessary to spin or de-spin the stator. By counter-rotating the stator at precisely the rotor's rate of spin the stator remains fixed in inertial space. The SBA also provides the means to articulate the scan platform, which is mounted on the stator, about the spin axis or "clock" direction. Electrical interfaces between the stator and rotor are contained within the SBA. These consist of slip rings for power transmission and rotary transformers for data transfer.

The Scan Actuator Assembly (SAS) is a bearing assembly with motor similar to the SBA. It is used to articulate the scan platform about an axis perpendicular to the spin axis, known as the "cone" direction. Thus, the scan platform can be pointed as desired by appropriate combinations of SAS and SBA motion commanded by the attitude control electronics. Both the SAS and SBA contain optical encoders which provide very precise position information. The ACE communicates with the SAS, SBA, gyros and accelerometers through the Despun Control Electronics (DEUCE) unit.



Attitude and articulation control subsystem (AACS) simplified functional block diagram

Wobble control of the Orbiter is achieved by changing the angle at which the RTG booms are canted to the spin axis. This is controlled by Linear Boom Actuators (LBA) which utilize stepper motors driven by the ACE.

The AACS must satisfy very stringent requirements imposed by the Galileo mission. In order to provide communication with Earth, the High Gain Antenna (HGA), which is aligned with the spin axis, must be pointed accurately. Control of the spin axis orientation is also important for the science instruments. Those on the scan platform must be pointed in a manner which corrects for spacecraft motion (wobble, nutation, etc.) as well as the relative angular motion between the spacecraft and a scan platform target (target motion compensation). Additionally, the fields and particles instruments mounted on the rotor require that the spin rate be carefully controlled. Probe release is initialized at a specific attitude and rate, also under the control of the AACS.

The AACS provides measurements of the Orbiter and scan platform attitudes and rates. Particularly remarkable is the fact that the AACS corrects this data for known errors that affect Orbiter and scan platform orientation and converts the information to the EME-50 coordinate system before it is telemetered (sent to Earth). This allows simplification of ground support systems, both in command preparation and pointing reconstruction, thus reducing operational costs.

The design of the AACS incorporates the ability to detect failures and switch to redundant components in order to continue as normal an operation as is possible in an anomalous situation. As was the case with other advanced planetary spacecraft such as Voyager, this is necessary because of the enormous distances and the attendant communications delays which could result in the loss of the spacecraft if there were no provision for self-diagnosis and correction.

— Ed Litty
George Carlisle

Spehalski (contd)

from inception through launch. He gained his earlier experience starting on the Sergeant missile system and continuing through the Mariner Venus and Mars missions.

Spe and his wife Nancy live in Altadena and have raised three sons, Steve, Mark and James. An avid sports fan, he likes to spend his spare time fishing (both lake and deep sea), boating, and camping with his family. He also plays handball several times a week to keep in shape, and tinkers with the old Corvair.

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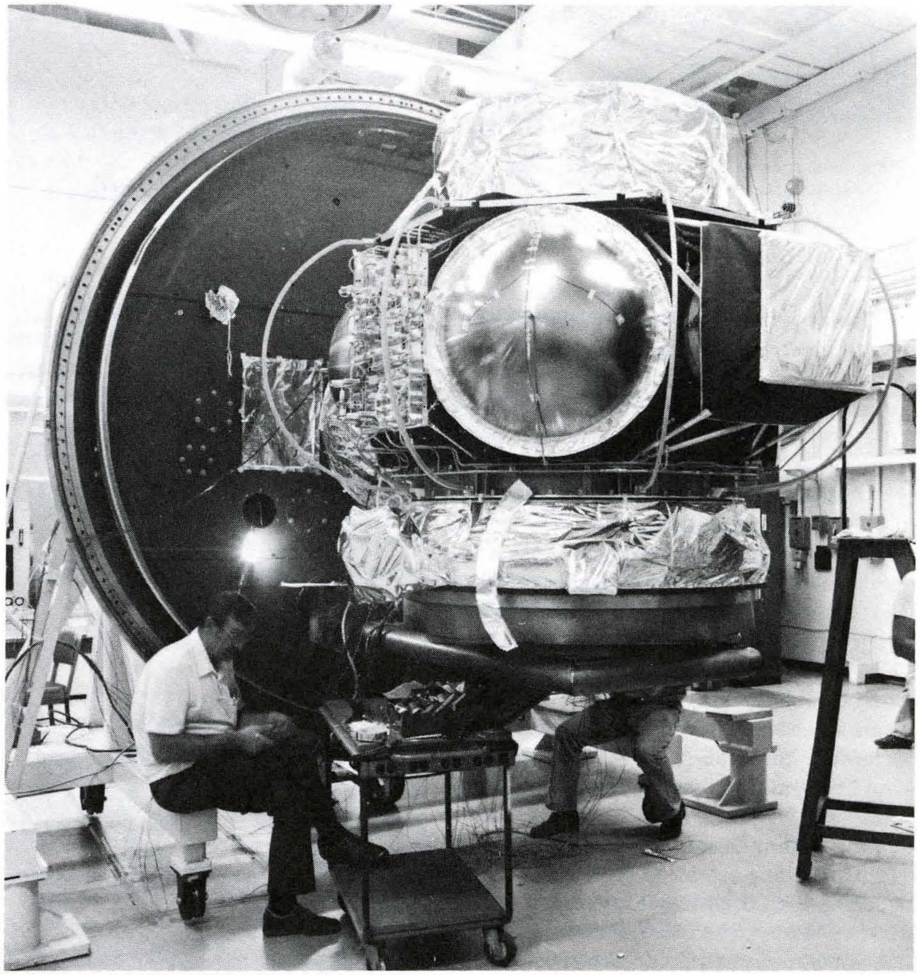
1625-101, Issue 6 March 1983

From the Project Manager

The 11th Project Quarterly Review took place on February 16, 1983. This was the first time that a quarterly review was held at Ames Research Center, which has the responsibility for the Galileo Probe. The emphasis of the review was on the Probe, so I will discuss the major Probe accomplishments since the last *Galileo Messenger.*

The flight Probe has been in system integration since the spring of 1982. Continued and more serious problems with the data and command processor (DCP) have impacted the system integration and test schedules. While the flight DCP problems are being resolved, the Probe is operating with the second DCP which has not completed final assembly and flight acceptance testing. As a result, limited environmental tests will start with the flight Probe and then it will be delivered to JPL on August 1, 1983 for initial system integration with the flight Orbiter. This should determine if any electrical problems exist. After a month of testing, the flight Probe will be delivered to the Hughes Aircraft Company (HAC) for installation of the flight DCP and final Probe System environmental tests. The flight Probe will then be returned to JPL in January 1984.



Retropropulsion module, mounted on the door of JPL's 10-ft vacuum chamber, undergoes thermal blanket fittings prior to thermal tests in the chamber.

Meanwhile, a structural test model (STM) Probe was delivered to JPL in December 1982, and it, along with the STM relay receivers and relay antenna, will be integrated on the Orbiter dynamic test model (DTM) to undergo structural testing of the spacecraft configuration during 1983.

Progress is also being made towards a second Probe drop test in July 1983, because of problems with the parachute opening experienced on the first drop test last year. Wind tunnel tests of the Probe and Probe/Parachute models will be done over the next few months to verify the correct parachute configuration before the drop test.

Various models of the Probe instruments have been integrated into the Probe and other flight and engineering models will continue to be integrated prior to environmental testing of the Probe. The qualification model and flight model relay receivers are into various phases of manufacture and testing. The qualification model will be made available to JPL on August 1, 1983 to support the electrical integration of the Probe and an initial end-to-end data test.

A decision was also made to improve the lithium battery header design to make it more resistant to high temperature corrosion. New cells will be manufactured and life testing will begin.

Integration and system test of the Orbiter starts at JPL in March 1983. The next 20 months will encompass the arduous task of checking, testing, and retesting the Spacecraft, learning its idiosyncrasies and preparing it, and ourselves, for flight.

– J. R. Casani

Orbiter's despun section receives its cabling and thermal blanket fittings.

Flight Cabling

Cables composed of nearly 25,000 feet of electrical wire and over 700 connectors that will go into the Galileo Orbiter are currently in fabrication at JPL.

"It takes about four months to cable the despun section, and about six months to do the spun section," explains Galileo's flight cabling cognizant engineer Clyde King of JPL's Space Program Engineering Section (352).

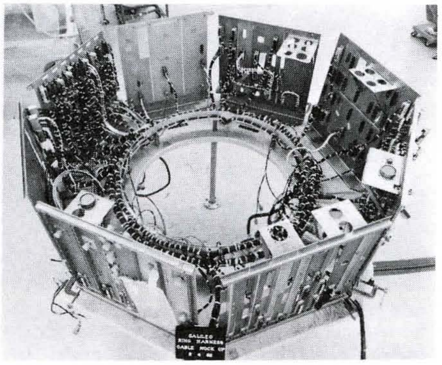
The cabling design began several years ago, using spacecraft drawings to determine the cabling needs. Fabrication began about a year ago.

The cabling task is exacting, requiring painstaking attention to details. Working with their hands and sometimes tweezers, the cabling team solders the wires to electrical contacts, routes the wires and ties them into bundles, and then sends the connectors to be potted – filled with a molding compound which holds the wires in place and also provides electrical protection.

Quality assurance inspections take place at every step. In-process inspections are performed on every solder joint, and electrical inspections look for shorts, open circuits, or high voltage breakdowns. Photographs are taken often to document each task.

A ring of cabling will interconnect the electronics bays of the Orbiter's spun section. Cabling for this spun bus ring harness begins with prewiring at a workbench, making "pigtails" with 30 to 40 percent of the electrical leads dangling. The harness is then put on a mockup of the bus and the wires are routed. The routing takes many weeks, since some connectors have as many as 50 wires going eight to ten different places on the spacecraft.

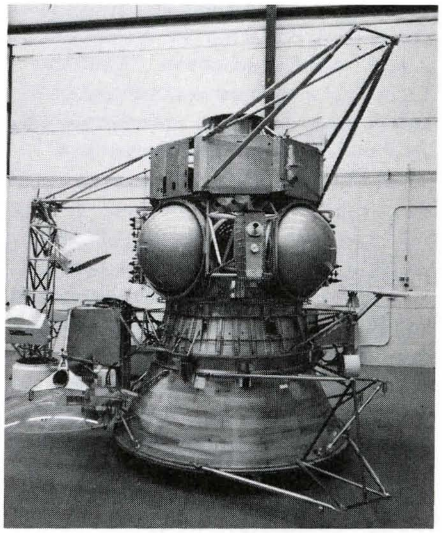
Every wire and connector is completely shielded to protect against Jupiter's severe radiation. A major goal is to prevent any possibility of undesirable effects from electrostatic discharges on the spacecraft. Such ESD could cause component damage or upset the onboard computers. Voyager, on its quick sprint through the Jovian system, experienced some ESD problems. Galileo will spend many months in this hostile environment, compared to Voyager's few weeks.



Cabling ring harness on the Orbiter's eight-sided bus.

Most of the wire insulation is Kapton®, chosen for its light weight and electrical characteristics. Teflon® is used in some areas of the spacecraft where different electrical characteristics are needed. Fiberglass sleeving is used on exposed cables for protection from micrometeoroids.

The cabling crew consists of about 15 experienced cable fabricators in the Fabrication Engineering and Services Section (357). The cablers have also gone to school at JPL to learn more about cable fabrication, soldering, potting, cleaning connectors, and crimping. They are currently working 60-hour weeks on a split shift schedule in order to deliver the spun bus cables to JPL's Spacecraft Assembly Facility (SAF) about March 7. Delivery of the despun and science cabling will follow later this spring. Engineering liasion for the cable fabrication effort is under the cognizance of Art Prisk. Lead technician in the cable shop is Patricia Westerlund.



Full-scale mockup of the Galileo Orbiter (minus its high-gain antenna) was assembled to aid in the configuration, cabling, and blanketing design.

The *Galileo Messenger* is meant for all members of the Galileo team, their families, and interested parties.

If you or an associate knows of someone who should receive the Messenger and is not, please return the coupon below to:

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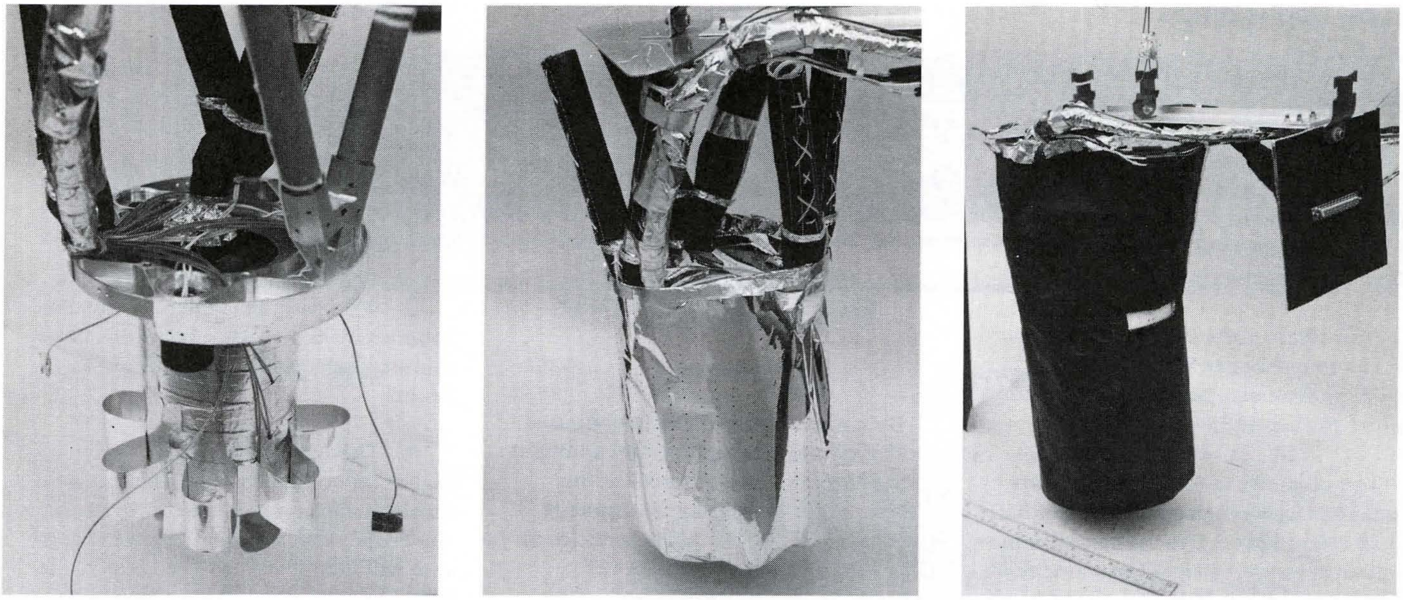


a) *b)* *c)*

Outboard magnetometer undergoes thermal blanketing: a) mylar meteoroid spacers are attached to the instrument, b) multiple layers of aluminized mylar and dacron net are attached over the spacers, and c) the black outer layer completes the blanketing.

Thermal Blanketing

One of the final subsystems installed on the spacecraft before launch – the thermal blanketing – is well along in the final design stages.

According to Hugh von Delden, cognizant engineer for the blanketing, there will be nearly 300 thermal blankets on the spacecraft covering virtually everything except for the radioisotope thermoelectric generators (RTGs), radio antennas, and selected radiating areas.

The blanketing serves several purposes. Not only does it retain heat to warm vital parts of the spacecraft, but it also protects against electrostatic discharge and micrometeoroid impacts. The blanketing on most of the spacecraft is spaced away from the surface of the equipment either by mylar standoffs or mechanical methods. This space provides a distance required to disperse the energy of an impacting micrometeoroid and thus prevent penetration of vital equipment. The blanketing serves as a breakup barrier against micrometeoroids up to 1/32 of an inch in diameter. Additional protection is provided in areas such as the fuel tanks, where one penetration could end the mission.

Blanketing on the retropropulsion module (RPM) will prevent the fuel and oxidizer from freezing. Excess power from the RTGs will be dissipated through shunt heaters in the RPM to maintain the necessary temperatures.

Thermal tests of the RPM have been performed in the 10-ft vacuum chamber at JPL. The "cold walls" – walls filled with liquid nitrogen – simulate the extremely cold temperatures of deep space, down to about -300°F.

Thermal tests of the temperature control model (TCM) full-up spacecraft are currently scheduled for January 1984 in JPL's 25-ft Space Simulator chamber. Solar thermal vacuum tests of the flight spacecraft are scheduled for the summer of 1984.

Unlike Voyager's magnetometer boom, Galileo's mag boom will be covered with a single layer of black blanketing to protect it from electrostatic discharge and micrometeoroids. Prior to launch, the boom will be collapsed in a cylinder about two feet long. After release from the Centaur upper stage, the boom will be deployed, extending to its full length of 36 feet. The single layer sock will be deployed with the boom structure.

The blanketing itself is a multilayer insulation. The portion nearest the spacecraft – its "thermal underwear" – consists of 10 to 20 layers of 1/4-mil thick aluminized mylar and dacron net, explains von Delden. The final two-layer covering is a black outer layer of 1-mil thick carbon-filled polyester coating on 1/2-mil Kapton ® over a single layer of 1-mil aluminized Kapton®. The black blanketing is conductive and grounded to meet the equipotential spacecraft requirements. Some spacecraft had been plagued by static discharge interpreted by the spacecraft as radio frequency signals. Unfortunately, this caused the spacecraft to do things they weren't supposed to do. The spurious signals were caused by electrical arcing resulting when a large differential charge exists between two surfaces. Galileo's blanketing has been designed so that there will never be more than 10V potential on the surface of the spacecraft at any time.

The blanketing process begins with a paper pattern which is fit to a model of the instrument or subsystem. The multilayer insulation is fabricated from these patterns and is installed on the spacecraft for a final fitting. Finally, the blanketing is laced into place – literally tied on in a time-consuming process. The final blanketing can be done only when the spacecraft has been fully assembled and prepared for launch at Cape Canaveral. A team of four to six people will work around the clock for two to three days to install the final blankets.

JPL's Instrumentation Section (351), Space Program Engineering Section (352), Applied Mechanics Technology Section (354), and Design and Mechanical Support Section (356) are involved in the design, development, and fabrication of the thermal blankets.

Probe Nephelometer

The nephelometer aboard the Galileo Probe will measure the physical structure of Jupiter's clouds, including the location of cloud layers and the size, concentration, and shape of cloud particles. The shape of the particles – spherical or nonspherical – indicates their state – solid (ice) or liquid.

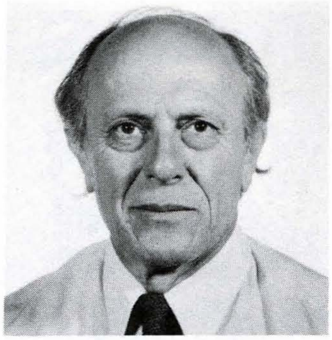
Instruments of a similar design flew on the four Pioneer Venus Probes in 1978, and are also being developed for future probes of Saturn and Titan.

The objective is to measure Jovian cloud particles ranging in size from 0.2 to 20 microns at 0.1 to 10 bars of atmospheric pressure. Densities greater than three particles per cubic centimeter will be measured, at altitude intervals less than 1 kilometer.

As the Probe falls through the atmosphere, it is expected to pass through two and maybe three major cloud layers. The highest layer, occurring at a pressure level of 0.2 to 0.5 bars, is composed primarily of ammonia. A haze of moderately small particles overlies this layer. Deeper into the atmosphere, where the pressure is about 1 to 2 bars, may lie a layer composed of ammonium hydrosulfide particles. Below these two, at a pressure level of about 2 to 5 bars, lies a third layer composed primarily of water particles. The cloud particles may be icy crystals in the higher, colder clouds, and liquids or melting solids in the lower, warmer cloud layers.

An understanding of the physical properties of the cloud particles is essential to understanding the planet's energy balance. Jupiter gives off twice as much heat as it receives from the Sun, despite the fact that it is nearly half a billion miles from our star. In fact, Jupiter nearly became a star itself. Instead, it is a giant ball of hydrogen and helium, with complex weather systems driven by its rotation and internal heat. It is important to learn about Jupiter's energy balance to understand its basic processes.

Information from the nephelometer, atmospheric structure instrument, and mass spectrometer will provide profiles of the atmosphere's composition, particulate properties, pressure, and temperature as a function of altitude. Exact information on the Probe's rate of descent will be required to compile these profiles.



Boris Ragent

By comparing the data to various models of the atmosphere and adding it to the information gathered by the Orbiter's remote sensing instruments, the characteristics of cloud particles at the Probe's entry site can be well defined.

The instrument consists of a forward scatter unit, a backward scatter unit, and electronics. Immediately after the Probe jettisons its parachute, the nephelometer will extend a 13-cm arm. The forward scatter sensing mirrors are located on the tip of this arm. As the spinning Probe drops through the clouds, cloud particles pass through a sampling volume defined by these mirrors and the illumination provided by an infrared laser beam. Cloud particle sizes are determined by the intensity of scattered light intercepted by the four mirrors positioned to detect light scattered at angles 5.8°, 16°, 40°, and 70° from the main beam. A heater unit on the mirror assembly aids in preventing condensation or frost formation during the Probe's descent.

The backscatter unit measures light scattering at an angle of 178° from the main beam. It is mounted behind the forward scatter unit and just clears the outer surface of the Probe's skin. It also uses an infrared laser beam to illuminate the particles.

The electronics unit is pressure-tight, while both the forward and backward scatter units are vented so that the internal pressure of the units essentially follows the pressure inside the Probe. The instrument mass is 4.4 kilograms, and it operates on an average 13.5 watts.

Principal investigator for the nephelometer experiment is Dr. Boris Ragent of NASA/Ames Research Center. There are also four co-investigators. The instrument was built by the Martin-Marietta Corporation of Denver, Colorado.

WWWWWH*

**Galileo's Project Information Coordinator, Joel Harris, begins a semi-regular column to answer commonly asked questions about the Project. (WWWWWH stands for Who, What, When, Where, Why, and How, the essential elements of any story.)*

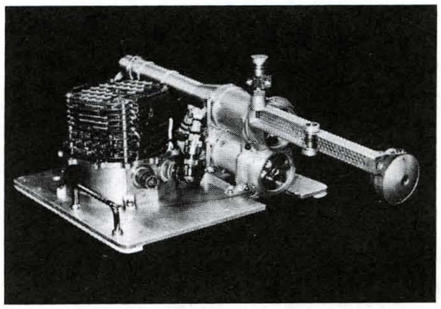
Q: Why will the Galileo Orbiter be spun-up from 3 to 10 revolutions per minute (rpm) prior to release of the Probe?

A: There are two reasons. First, a higher rate of spin will ensure a more stable platform from which to release the Probe, and second, the greater spin rate will help "aim" the ballistic Probe into Jupiter's atmosphere (much like the rifling in a gun barrel causes the projectile to spin and travel more precisely to its target). The Probe must be precisely aimed at release because it has no propulsive system of its own and cannot be communicated with or its course altered after release from the Orbiter.

Q: What are the nominal electrical power usages for the Galileo Orbiter during the encounter and cruise phases of the mission? What is the strength of the downlink signal?

A: The two radioisotope thermoelectric generators (RTGs) mounted on the Orbiter deliver 570 watts at launch and 486 watts at the end of six years, nominally. The Orbiter itself uses 400 to 430 watts during the "quiet" cruise phase and 520 watts during the Io science phase of the mission.

The downlink signal from the Orbiter averages a scarce 20 watts – about the strength of the lightbulb in your refrigerator. It must travel half a billion miles to Earth where it is received by the antennas of the Deep Space Network.



Probe Nephelometer

The Galileo Messenger

1625-101, Issue 7 June 1983

SAF Activities

Integration and test of the Galileo spacecraft is a complicated process that requires nearly as much time as the prime mission itself, to ensure a successful mission.

Completion of the spacecraft flight acceptance program is scheduled for October 1, 1984. Completion means that all design verification requirements have been satisfied, all functional and environmental tests have been performed, and all scheduled intersystem testing (mission operations system to spacecraft, spacecraft to Space Transportation System) has been accomplished. In short, the spacecraft could be committed to flight at that point.

Subsystem integration and test of the Galileo Orbiter began in JPL's Spacecraft Assembly Facility (SAF)

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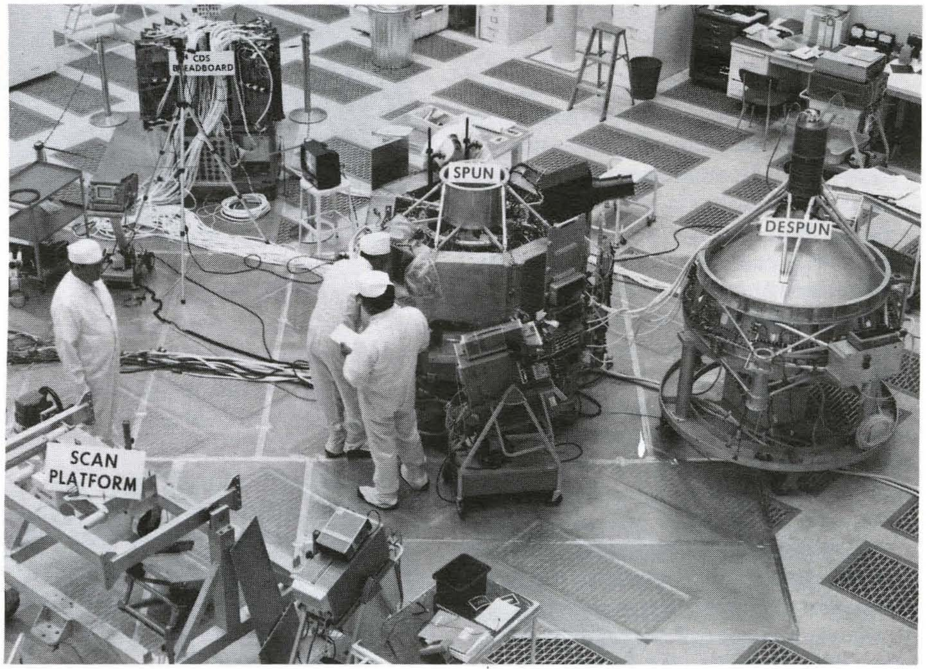
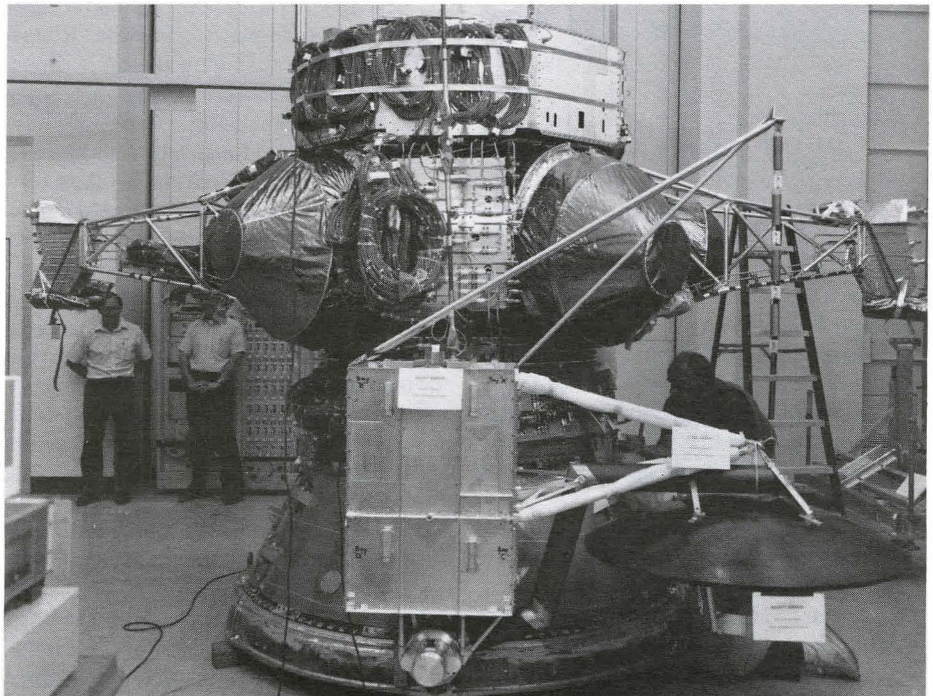


The Orbiter subsystems are electrically integrated in SAF. Personnel wear "bunny suits" and follow special robing procedures to avoid electrostatic discharge.



Development Test Model is readied for cruise configuration modal test in JPL's Environmental Laboratory

Development Test Model

The Development Test Model (DTM) is the structural twin to the flight spacecraft being assembled in SAF, but it does not include the electronics or other flight equipment. It is used for testing to verify the structural analyses used in the design of the spacecraft.

Assembly of the DTM began in March 1983, and testing began in May. Tests include modal tests in the cruise and launch configurations, acoustic and pyro shock, and static tests.

The three-day cruise configuration modal test was completed on May 25. The object of this test was to look for natural vibrations of the spacecraft that affect the control of the spacecraft in cruise. The test was run to determine the key structural parameters. This information is then used by the

see page 3

SAF Activities . . .

(Bldg. 179) in mid-March 1983. Contractors from across the country have been involved in developing and fabricating (building) pieces of the spacecraft. Before delivery to SAF, each engineering subsystem and science instrument has been tested, qualified, and accepted for flight. In SAF, these units are mechanically and electrically integrated to become a functioning spacecraft.

SAF consists of two environmentally-controlled clean rooms, the adjoining System Test Complex area, and office space. The Orbiter is being assembled in High Bay 2. The clean rooms are constantly controlled at 72°F and 50 percent humidity, and the air is cleaned with high efficiency particulate air filters. Special procedures eliminate the possibility of electrostatic charging of personnel and equipment that might come in contact with sensitive electronics.

Cabling from the spacecraft hardware in the clean room is routed to the System Test Complex, where engineers monitor and control the testing. (Visitors may view this area, but are asked to stand in the designated areas.)

Mechanical assembly and electrical integration of each flight-qualified subsystem into the Orbiter includes verifying the interfaces and functionally testing the subsystems as a unit while using Orbiter power, telemetry, and commands.

Orbiter subsystem integration and test will continue through this summer. The retropropulsion module (RPM) will be electrically integrated later this year. The remaining flight subsystems will also be integrated and tested this summer. In September, the Probe will be electrically connected to the Orbiter for the first time, and an end-to-end Probe data link test will be performed. This test will verify the overall data flow from the Probe to the radio relay hardware on the Orbiter, to the Orbiter command and data system, to the Orbiter modulation/demodulation system and radio transmitter, from the Orbiter to the Earth-based tracking systems, to the Orbiter and Probe ground data systems, and finally to the scientists for analysis.

Engineers in SAF's System Test Complex monitor testing of the Galileo Orbiter

The Probe will then return to Hughes for further environmental testing, and will be returned to JPL in January 1984.

Meanwhile, with all flight subsystems integrated and tested, Orbiter system tests will begin in October 1983. Baseline tests are run to accumulate data on the behavior of the Orbiter. The baseline test will be run repeatedly throughout the test program.

Interference tests will determine if any subsystem has any adverse effects on any other subsystems.

Mission profile tests will be performed to simulate activities for key mission phases such as launch, trajectory corrections maneuvers, cruise, Probe release, and insertion of the Orbiter into orbit around Jupiter. Operational capabilities will be explored, to see what the Orbiter can do, in addition to what it must do.

System level testing of the combined Orbiter and Probe will begin in January 1984, followed by environmental tests next spring. The goal is final flight acceptance by October 1984. Shipment to Florida will be in January 1986 in preparation for launch in late May 1986.

Galileo's flight system integration manager is Dick Spehalski. Milt Goldfine is chief of test and operations, while Warren Moore is the deputy. Coordination is provided by the Project Test and Operations Section (374), with support from the technical divisions and the quality assurance organization.

Ultraviolet Spectrometer

The ultraviolet spectrometer onboard the Galileo Orbiter will study properties of Jupiter's high atmosphere; the Galilean satellites Io, Europa, Ganymede, and Callisto; and the doughnut-shaped cloud of ionized plasma that surrounds Io.

Observations in the ultraviolet range of the spectrum yield composition information that cannot be obtained any other way.

The UVS will be mounted on the movable scan platform of the Orbiter, its aperture aligned in the same direction as the other remote sensing instruments (the imaging cameras, photopolarimeter radiometer, and near infrared mass spectrometer). Their data, taken together, will provide a comprehensive picture of many aspects of the Jovian system.

The UVS instrument's wavelength range of 1150 through 4300 Angstroms overlaps and extends the range available on the Voyager spacecraft and heightens the probability of discovering new ultraviolet phenomena.

Voyager measured a northern polar aurora on Jupiter that extended 30,000 kilometers. These auroras occur when electrons and ions spiral into the atmosphere along the planet's magnetic field lines that also intercept Io. The impact causes the dominant gases in the atmosphere – atomic hydrogen, molecular hydrogen, and helium – to light up. The intensity of the ultraviolet emissions is a

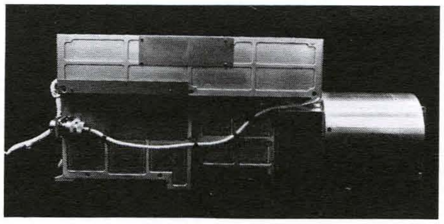
measure of the vertical distribution of the gases in the atmosphere.

Emissions over the planet as a whole occur because of sunlight and electron impacts. These "airglow" emissions can tell much about the structure of the upper atmosphere.

Galileo's UVS will look for complex molecules in Jupiter's atmosphere. Such complex molecules are destroyed by solar ultraviolet light, and the spectrum of scattered ultraviolet light is imprinted with a distinctive "fingerprint" of the molecule that was destroyed. Acetylene has been identified on Jupiter in this manner. It is important to identify such complex molecules to understand if complex hydrocarbons might be present on Jupiter. These hydrocarbons are the "building blocks" for life on Earth, and confirmation of their presence on another body in the solar system would have far-reaching implications.

During the Orbiter's twenty-month, twelve-orbit tour of the Jupiter system, it will map the Galilean satellites extensively. The UVS will look for evidence of atmospheres – an indication that volatiles are escaping from the moons and that their compositions are still evolving. The UVS will also search reflections from the satellite surfaces for evidence of ammonia, ozone, and sulfur dioxide. The UVS can measure hydrogen, oxygen, nitrogen, carbon, sulfur, calcium, lithium, magnesium, molecular nitrogen, nitric oxide, hydroxyl, carbon monoxide, cyanogen, and sulfur dioxide, as well as ions of molecular nitrogen, carbon monoxide, carbon dioxide, and magnesium.

Volcanic eruptions on Io are believed to be the source of a large doughnut-shaped cloud of ionized sulfur and oxygen that encircles Jupiter along the orbital path of Io. Temperatures of the sulfur and oxygen ions in this plasma torus can be more than ten times the temperatures at the surface of the Sun. These ultraviolet observations, along with the direct measurements of the ions



Ultraviolet spectrometer

and electrons in the Io torus by the fields and particles instruments and observations of Io's volcanic activity by the imaging system, will provide a comprehensive picture of Io's evolution and relationship with Jupiter's magnetic field.

The ultraviolet spectrometer, developed and built by the Laboratory for Atmospheric and Space Physics at the University of Colorado, consists of a 250-mm Cassegrain telescope, a 125-mm monochromator, three photomultipliers, and control logic within an onboard computer. The instrument weighs about 4.2 kilograms and uses 4.5 watts of power. It scans one of three channels in the wavelength range of 1150 to 4300 Angstroms in 4-1/3 seconds, and its counters are read and data is transmitted to Earth at 1000 bps.

Principal investigator is C.W. Hord of the University of Colorado. Five co-investigators are members of the UVS team.

Dr. Charlie Hord

Development Test Model ...

attitude control analysts in the mathematical model software which simulates the flight of the spacecraft in cruise.

For this test, the DTM was suspended from a crane and the spun and despun sections were separated as they will be in cruise (by about 3/16-inch) but prevented from spinning. Small exciters were used to vibrate the spacecraft, providing data on the natural frequencies and other structural parameters of the spacecraft. At this point, the DTM did not include the Probe, booms (science, RTG, magnetometer), high gain antenna, or adapters to the upper stage engine, and the propellant tanks were empty. The absence of these elements during the test is later analytically corrected for in the math model software.

The DTM is now configured for the six-week launch modal test from June 6 to July 25. All loads-carrying structures are identical to those that will be on the flight spacecraft. The high-gain antenna, Probe, and all booms are installed, and mockups of the science instruments and electronics simulate their mass. Alcohol and freon simulate the mass of the fuel and oxidizer in the retropropulsion module. The DTM with its adapters is attached to a base just as it will be attached to the Centaur upper stage. It is bolted to a seismic block – a block of concrete sunk about 14 feet into the ground to avoid interference from outside vibrations such as passing trucks – in the modal pit. (The pit is about 3 feet deep.) Again, exciters are used to vibrate the spacecraft to identify natural frequencies and other structural parameters. As many as 180 accelerometers and 350 strain gages will also supply data (in flight, the spacecraft will have only 6 to 12 accelerometers). This test data is used by analysts in the Applied Mechanics Technology Section (354) to verify the math model and launch loads predictions.

The DTM will next be moved into the Environmental Laboratory's acoustic chamber where it will be exposed to the noise levels the flight spacecraft will experience in the Shuttle's payload bay. Very large horns – about four feet on a side – will create an average of 147 decibels in the chamber, while microphones placed around the DTM will

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From the Project Manager

It is personally exciting for me to follow the progress of integration and test of the flight spacecraft, as well as the DTM activities. Drop by the second-floor viewing gallery of High Bay 2 in SAF to watch the progress (the entrance is at the southeast corner of Bldg. 179). The DTM will also be available for viewing later in the summer.

Since then, work has steadily progressed on electrically integrating the engineering subsystems and science instruments. Where flight equipment is not available yet, engineering models or prototypes are being used for testing in order to uncover any existing design problems.

Integration of engineering subsystems through mid-June includes the spun and despun flight cabling; the flight power subsystem; the breadboard command and data subsystem (CDS); non-flight spun and despun structures; the attitude and articulation control subsystem (AACS) engineering development model, including the attitude control electronics (ACE), the despun attitude control electronics (DEUCE), propulsion drive electronics (PDE), star scanner, acquisition sensor, and linear boom actuators (LBAs); the flight radio frequency subsystem (RFS); and the engineering model modulation/demodulation subsystem (MDS). Science instruments integrated thus far include the dust detector subsystem (DDS), magnetometer (MAG), and photopolarimeter/radiometer (PPR).

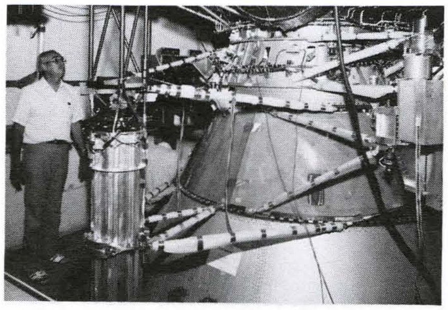
Delivery of the Probe to JPL has been delayed about six weeks due to the discovery of contaminants in the data and command processor. The CDS and AACS integration has been hampered by late software deliveries and flight hardware fabrication problems. Planning is in process to allow completion of the flight acceptance test program as scheduled by October 1, 1984.

Concurrently with buildup and test of the Orbiter, testing of the Development Test Model has begun. The cruise modal test has been completed, and the spacecraft is currently configured for the launch modal test. The acoustic and pyro shock tests will follow later this summer.

We also have a new program manager at NASA Headquarters. Harry Mannheimer comes to the program from Landsat. Former program manager Al Diaz is now the Deputy Director of NASA's Earth and Planetary Exploration Division.

– J. R. Casani

Development Test Model . . .



DTM in modal pit

pick up the noise levels. The acoustic tests will take about three days.

Pyro shock tests will require about two days. In flight, explosive bolts and cords will release booms, instrument covers, the Centaur, and the Probe. The shock waves from these explosions will be measured during the test to evaluate the effect of these pyrotechnic (gunpowder) devices on the rest of the spacecraft.

About the first of September, the DTM will be moved to the static test tower (Bldg. 280) for 10-weeks of static tests conducted by the Applied Mechanics Technology Section. Results of Shuttle flights to date, together with the Galileo mathematical model software, have been used to predict what the structural loads will be on the Galileo spacecraft. The test will be conducted to these predicted loads. Hydraulic loading devices (rams) will be used to pull on the spacecraft structure, and data will be accumulated through strain gages, load cells, and deflection transducers.

Frank Tillman is test manager for the DTM. Test directors for the individual tests are Marc Trubert, cruise and launch configuration modal tests; Dennis Kern, acoustic and pyrotechnic tests; and Jim Staats, static test.

Note to Galileo team members at JPL: To cut down on distribution costs, *The Galileo Messenger* is now being distributed to you through your Galileo Division Representative.

Meet the Team

Larry Colin wears many hats. He is the Chief of the Space Science Division at NASA/Ames Research Center, the Project Scientist for Pioneer Venus, and the Probe Project Scientist for Galileo. With Torrence Johnson, Galileo Project Scientist, he works to assure that the atmospheric scientific objectives of the Probe mission will be accomplished and that they mesh with the results to be gathered by the atmospheric measurements made by the Orbiter. At Ames, Larry works closely with the Galileo Probe Project Team, led by Joel Sperans, and with the Probe Principal Investigators. Here, spacecraft, scientific instruments and Probe mission planning all come together to yield a package that will provide in 1988 an hour of unique scientific data.

Larry's participation on Pioneer Venus, which began in 1971 and continues to this day, naturally led him to his current role with Galileo in 1977. Several of the Galileo Probe scientific instruments are descendants of those that flew on the Pioneer Venus Multiprobe Mission in 1978.

Larry obtained his BSEE degree from the Polytechnic Institute of Brooklyn in 1952, an MSEE from Syracuse University in 1960, and a PhD in electrical engineering from Stanford University in 1964.

Larry and his wife, Roberta, live in Palo Alto. Roberta owns and manages an employment agency with offices in Santa Clara, Palo Alto and San Mateo. Their son, Lee Edward, manages the Santa Clara operation, while daughter Lisa Maria is also employed in personnel work at a small firm in the "Silicon Valley."

Dr. Larry Colin

The Galileo Messenger

1625-101, Issue 8 October, 1983

From the Project Manager

Major milestones were achieved in the integration and test areas this summer, well within schedule.

In the Spacecraft Assembly Facility, integration and testing continues with the hardware and software for the spacecraft's command and data subsystem (CDS) and attitude and articulation control subsystem (AACS), as well as with science instruments. The protoflight units of the plasma subsystem (PLS), solid-state imaging subsystem (SSI), magnetometers (MAG), near-infrared mapping spectrometer (NIMS), and ultraviolet spectrometer (UVS) were delivered to SAF and integrated on the spacecraft. (The photopolorimeter (PPR), dust detector subsystem (DDS), energetic particles detector (EPD), and plasma wave subsystem (PWS) had been delivered earlier.) Assembly of the flight despun bus, lower Centaur adapter, radio relay antenna (RRA) boom structures, and flight scan platform was also completed.

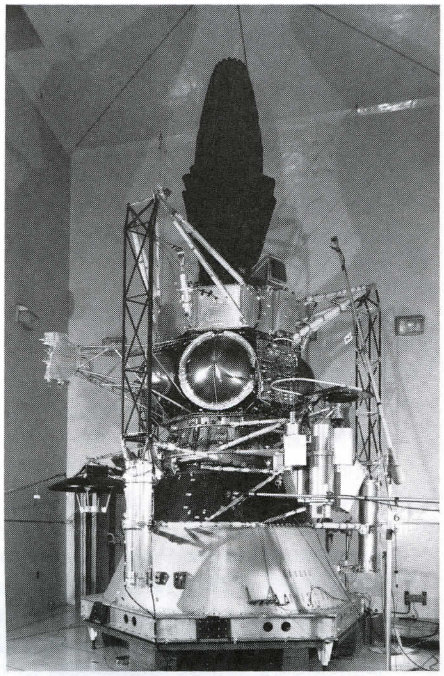
Environmental testing of the Development Test Model (DTM) continued as the spacecraft underwent cruise and launch modal, acoustic, and pyro shock tests. The DTM is now undergoing static tests to verify structural loads.

In late July, the second drop test of the Probe validated the corrected parachute shroud configuration. In September, the protoflight Probe was electrically connected to the Orbiter system for the first time as end-to-end data tests were conducted. Work continues at Hughes Aircraft on the flight unit of the data and command processor.

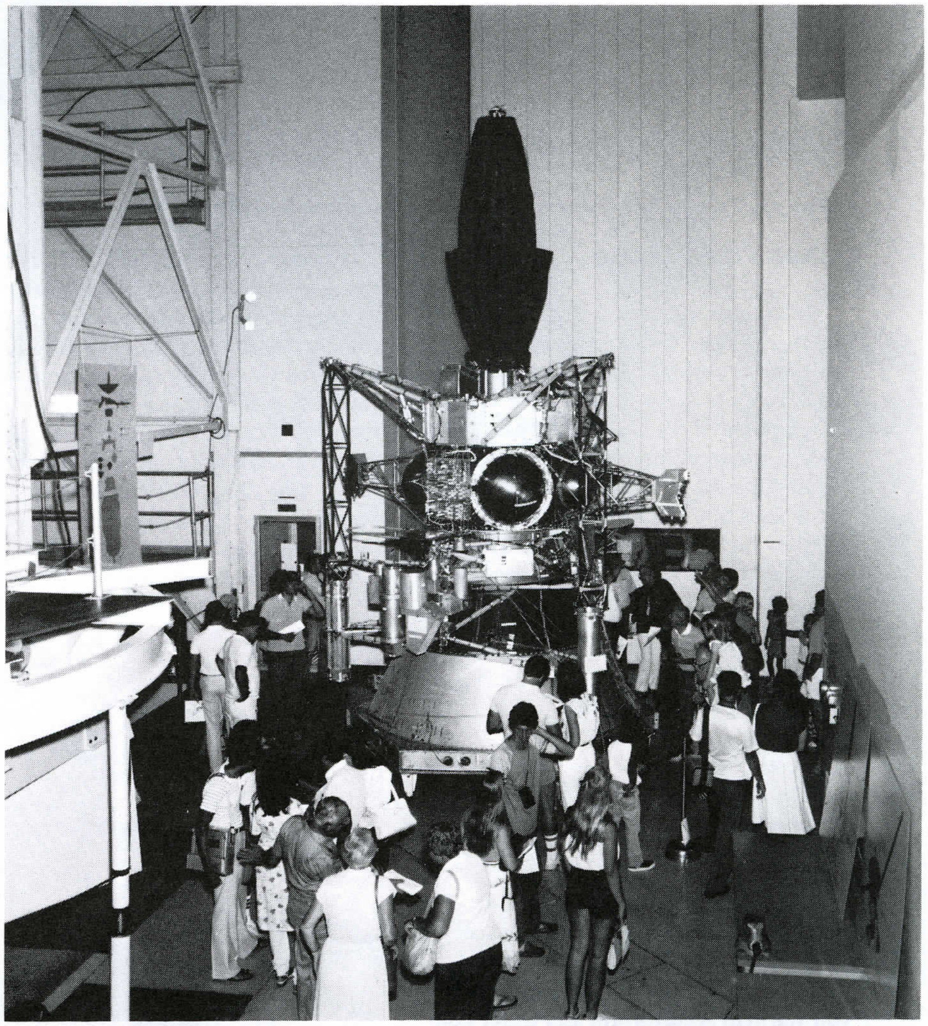
Participants in the Heavy Ion Environment Workshop at JPL discussed the threats presented by the heavy ions in the regions surrounding Io, and helped the Project establish a design model environment. On the basis of this information and extensive system, subsystem and component part analyses, the Project established a plan to prevent single-event upsets in this environment.

Many of you turned out for the showing of the DTM at our August Open House, and enjoyed the opportunity to show off your work to your families and friends. In both size and complexity, it is an impressive spacecraft.

– John Casani



Microphones placed around the DTM in the acoustic chamber pick up the noise levels created by large horns to simulate noise levels in the Shuttle's payload bay.



Team members and their families take a close-up look at the full-scale test model of the Galileo Orbiter

Over 1500 people signed sheets which will be reduced and sent to Jupiter on the spacecraft

Galileo Open House

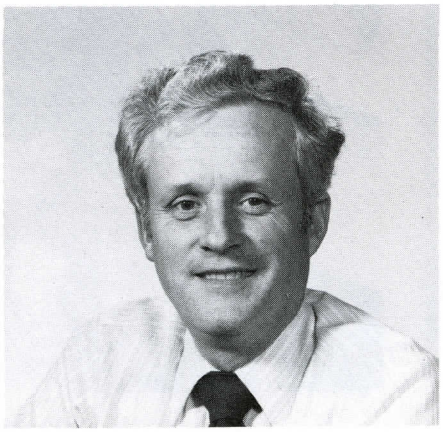
On August 14, over 1,500 invited members of the Galileo team at JPL, their guests and families, visited the Laboratory to view the full-scale Galileo Development Test Model (DTM). The DTM is the structural twin to the flight spacecraft now being assembled at JPL, but it does not include the electronics or other flight equipment. It is used in testing to verify the structural analysis used in the design of the spacecraft.

The spacecraft was situated in the open area between the acoustic chamber (where sound and pyro shock tests had been completed only a few days previously) and the modal pit inside the Environmental Lab (Building 144).

In addition to viewing the DTM, guests were invited to visit the Space Flight Operations Facility (Building 230) and see multi-media slide shows in von Karman Auditorium and other conference rooms. More mission information was available in the mall.

Perhaps the most popular activity of the day, however, was the opportunity for guests and employees alike to personally "send their name to Jupiter" on-board Galileo by signing large sheets that will eventually be photographically reduced onto aluminum plates and placed aboard the Galileo spacecraft itself. For those who missed the opportunity to sign up, there will be further opportunities to do so in the next 2-1/2 years before launch.

— Joel Harris



John Givens

Meet the Team — John Givens

John Givens is a man of many talents. As the Galileo Probe hardware manager at Ames Research Center, he has a vital role in the fabrication and delivery of the atmospheric probe.

Along with a team of Ames engineers under him, John is responsible for the day-to-day management and monitoring of the Probe development by the Hughes Aircraft Company. In addition, he is responsible for the hardware interface with project management at JPL. Thus, his job is a marriage of both technical challenges and personal interactions. The latter, he says, is the most challenging part, as human behavior is never as predictable as that of hardware.

He reports that the Probe work is progressing well, and that the data and command processor (DCP) problem is being resolved so that all the schedule milestones can be met. In fact, he says, it is the very maintenance of a schedule, set goals, and the challenges of daily crises that enable him to enjoy his project work so much.

Originally a music major at the University of Washington and the Curtis Institute of Music, John decided to switch to physics. After graduating from Washington, he went to work at Ames in 1961 doing research in high-speed entry and ballistic heating characteristics of projectile forebodies. He was also involved in meteor research during this time. He next worked on the Pioneer Venus mission as a thermal engineer, and was also a science engineer on the spacecraft.

John met his wife Dorothy while both were playing with a church orchestra in Philadelphia. They live in Sunnyvale with their two sons, while their daughter, a student at the University of California at Irvine, is spending the current school year in France. John still plays bassoon and gives private lessons. His playing is a relaxing contrast to his busy workdays at Ames, although his students sometimes require him to apply some of his management skills. Dorothy also gives flute and piano lessons privately.

Single Event Upsets

As a result of volcanic action on Io, the innermost of the large Galilean moons of Jupiter, particles (actually heavy ions) of sulphur and oxygen are present in the space surrounding the planet. These particles form a part of the Jovian magnetosphere. Although the origin of these particles is the moon Io, the volcanoes provide enough velocity for them to escape from the gravitational field of the moon and to become elements of the magnetosphere around Jupiter.

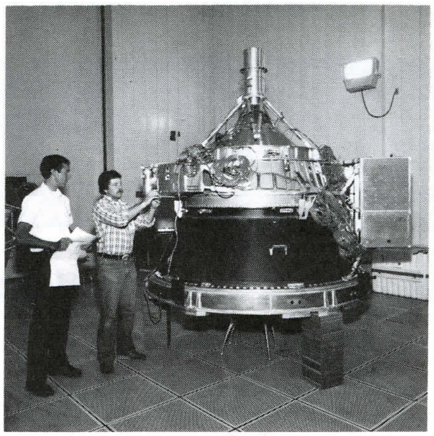
The heavy ions diffuse both inward and outward from the planet. Many of the particles diffuse outward to 20 to 50 times the radius of Jupiter (R_J, measured from the planet's center), where they are accelerated by an interaction with the massive Jovian magnetic field. Having been highly energized, these particles begin to diffuse away from the region of energization, once again some going inward and some outward. The outbound ones are of no concern, but the inbound ones get accelerated even further by the increasing magnetic field.

The most critical phase of mission operations for Galileo occurs at the time of the spacecraft's closest approach to Jupiter (4 R_J). The major mission events take place during this critical phase – the transmission of the Probe data to the Orbiter, followed by the relay of that data to the Earth, and the Jupiter Orbit Insertion (JOI) maneuver that slows Galileo into an orbit around the giant planet. It is during this critical phase that the energetic particles of sulphur and oxygen are a threat to Galileo. These heavy ions are capable of penetrating the delicate electronics in the spacecraft and causing a stored computer bit to change its value from a "0" to a "1" or vice-versa. This "bit flip" is referred to in engineering jargon as a Single Event Upset (SEU). A single bit flip in one of Galileo's computer memories could trigger a chain reaction of erroneous commands with disastrous results.

Over a year ago, the Project started its detailed study of the SEU phenomenon. The study was directed at understanding not only the heavy ion environment around Jupiter based on Voyager data, Pioneer data, and theoretical models, but also the impact of possible SEUs on the Galileo spacecraft and mission. In August this study was finished. The conclusions of the study were that, for the current Galileo spacecraft design, the probability of a mission catastrophe due to an SEU in either the Attitude and Articulation Control Subsystem (AACS) or the Command and Data Subsystem (CDS) was unacceptably high.

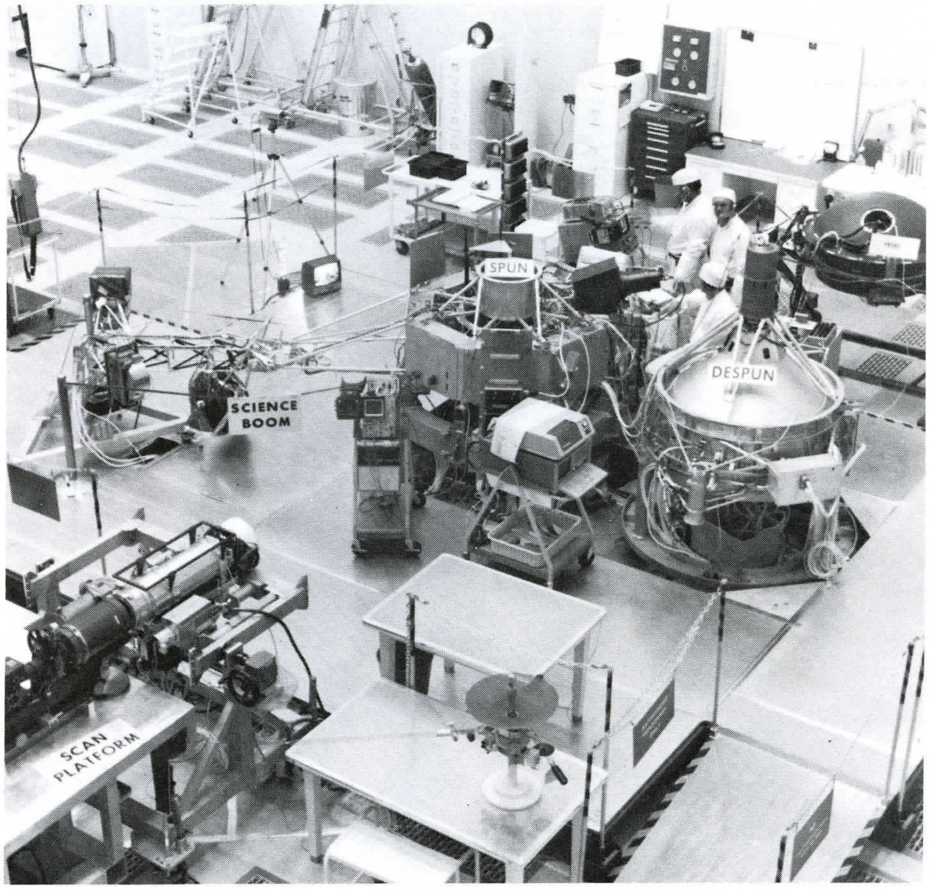
As a result, the Project has embarked on a major development of a new processor for the AACS that will not be sensitive to the sulphur and oxygen particles that can cause SEUs. In addition, two key part types in the CDS will be replaced with new part types to make that subsystem immune to Single Event Upsets. During the next year, these new activities for both the AACS and the CDS, together with the previously scheduled system testing activity, will provide significant challenges to the Galileo team.

– Gentry Lee



Central portion of DTM (top) with spin bearing assembly exposed.

Note to Galileo team members at JPL: To cut down on distribution costs, *The Galileo Messenger* is now being distributed to you through your Galileo Division Representative.



In mid-September, the Probe was brought to SAF from Hughes for 2 weeks of tests with the Orbiter.

The Galileo Messenger is published quarterly in March, June, September, and December.

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Typesetting & Layout . . . . JPL Graphics Services
Printing . . . . JPL Printing Service
Galileo Project Information Coordinator . . . . Joel Harris

WWWWWH*

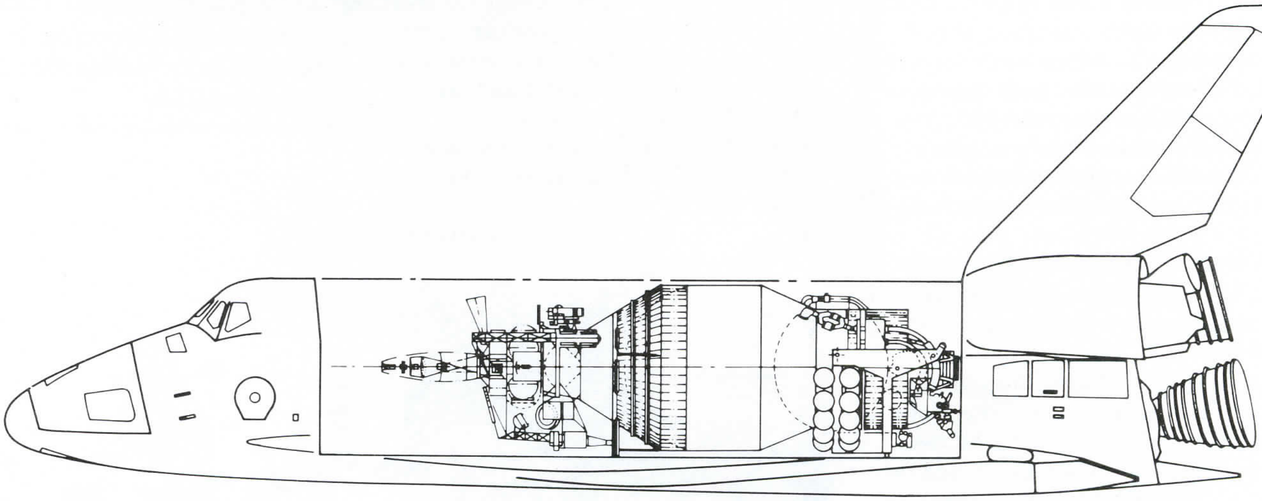
(*Who, What, When, Where, Why, and How)

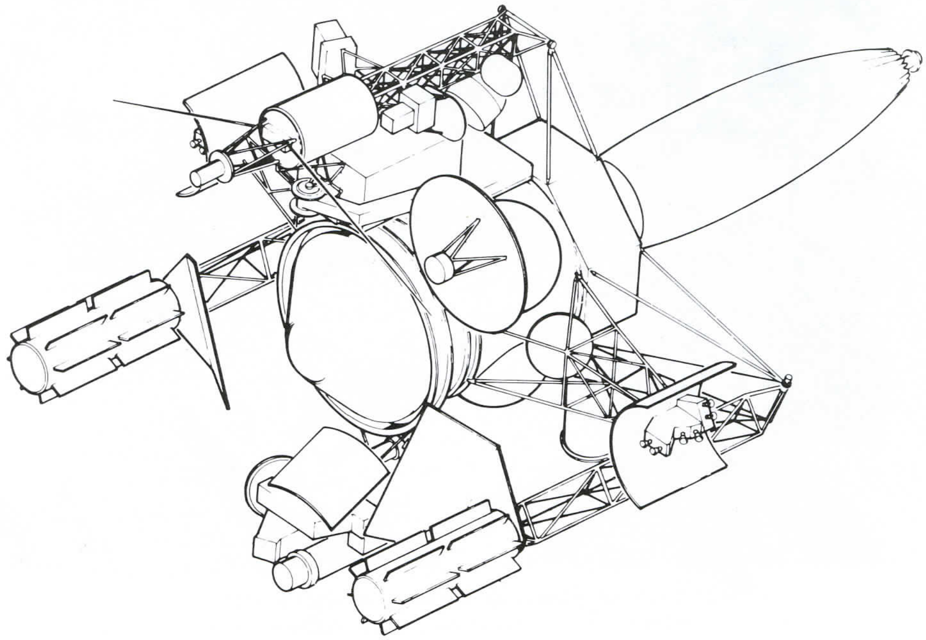
Q.: How deep will the Galileo Probe penetrate into Jupiter's atmosphere, and what factors will limit its performance as it descends to the deeper regions?

A.: The Probe is designed to successfully return data to a depth of 10 bars – ten times the atmospheric pressure at Earth's sea level. It is estimated that the Probe will reach this level about 40 minutes after entering the atmosphere, at a depth of about 90 kilometers below the one-bar level. The combination of increasing temperature and pressure will affect the behavior of selected subsystems as the Probe descends deeper into the atmosphere, but the critical elements are the Probe's battery, which supplies power, and the radio relay link to the Orbiter (including the transmitter, antennas, and environmental factors such as turbulence). Current estimates indicate a high probability that the Probe will still be operating at 20 bars (estimated to be at a depth of about 130 kilometers), and the Orbiter will be ready to continue listening to the Probe for as long as 75 minutes to capitalize on this "extended Probe mission." Eventually the Probe will be crushed and then melted as it continues to fall deeper and deeper into the ever-increasing temperature and pressure depths of Jupiter's atmosphere.

Q.: What will happen to the Galileo Orbiter after its nominal 20-month, 11-orbit mission?

A.: Many factors enter into the answer to this question. However, factors such as the accumulated amount of radiation received while orbiting Jupiter, collisions with high-energy atomic particles, and the amount of maneuvering propellant remaining will help decide the fate of the Galileo Orbiter. Depending upon the "health" of the engineering subsystems and science instruments on-board Galileo, the spacecraft could continue to encounter satellites, observe Jupiter's polar regions, or fly through the "dusk" region of Jupiter's magnetosphere. In time, Galileo's orbit may eventually decay and the spacecraft might spiral into Jupiter's atmosphere like some Earth-orbiting satellites do from time to time.





Above: Artist's rendering of Galileo stowed aboard the Space Shuttle.

Left: Galileo in launch configuration, with all booms and antennas stowed.

NASA
National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

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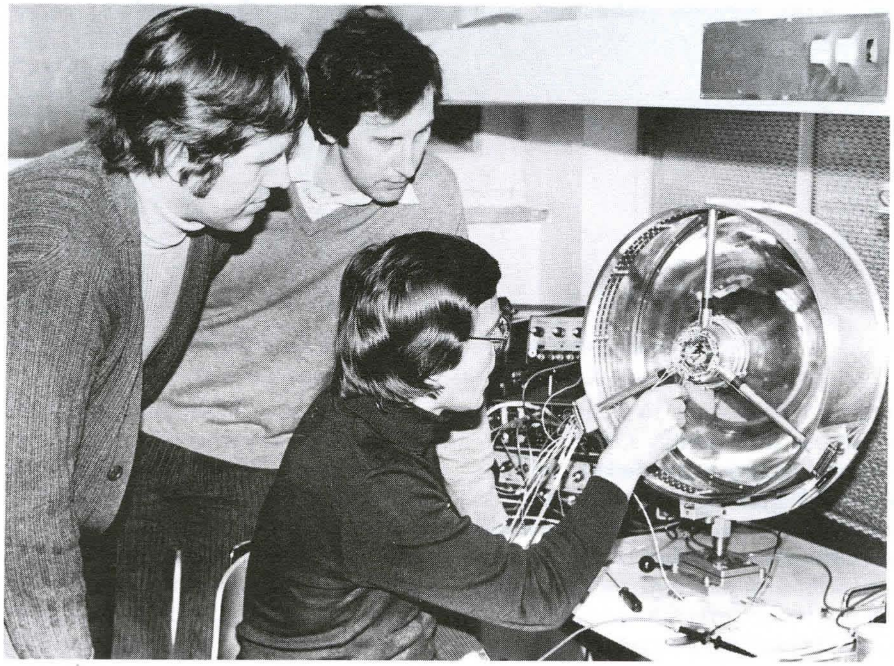


MPIK

Dr. Eberhard Grün (left), principal investigator, and Dr. Gregor Morfill, co-investigator, with Dietmar Linkert (seated), principal engineer, inspect the engineering model of the dust detector at MPIK.

Dust Detection Experiment

Jupiter, like Saturn and Uranus, is a ringed planet. The rings of both Saturn and Uranus were discovered from Earth-based telescopic observations, but Jupiter's rings are invisible to Earth-based instruments. In fact, their discovery hinged on a single photograph by Voyager 1, when the Sun's rays backlit the dust particles and made them visible to Voyager's sensitive cameras. "Particles" in Saturn's rings range from dust to the size of houses, but Jupiter's ring is believed to be composed entirely of dust particles.

The Galileo orbiter will carry an instrument designed to measure dust stream motion in the vicinity of Jupiter. The dust detection instrument will be mounted on the spinning portion of the orbiter.

Jupiter's rings are composed of three elements: the visible ring composed of micron-sized particles which extends about 7000 kilometers broad and less than 30 kilometers deep; a faint disk extending from the inner edge of the visible ring all the way to the planet's atmosphere; and a halo which extends more broadly and has a depth of about 100,000 kilometers.

What is the source of the particles in the rings? Current theory suggests that the micron-sized particles in the visible ring probably result from high-velocity impacts between small projectiles. Io's volcanoes probably supply the force needed to inject large quantities of fine particulates into Jupiter's plasma environment. If this theory is correct, there should be a "dust wedge" extending about 10° above and below the jovian equator out to about 700,000 kilometers (near the orbit of Europa). This is at a distance of about 10 jovian radii (R_J) from the planet's center. Io is at about 5.9 R_J.

The dust detector will be able to measure the size distribution, spatial

See page 3

From the Project Manager

NASA recently made the decision to commit a launch pad at Kennedy Space Center for Shuttle/Centaur match mate tests from January through May 1986. This is an especially important move since the launches of Galileo and the European spacecraft of the International Solar Polar Mission (ISPM) will be the first to use the Centaur G′ high energy upper stage, and these launches go off within days of each other in May 1986. At this writing, the Solar Polar launch period opens on May 15, while the Galileo period opens on May 20. There is no margin for error with either the Centaur or its interfaces with the Shuttle and the spacecraft. This commitment by NASA will impose some constraints on launch planning for the Shuttle during that period. I believe this decision reaffirms the strong commitment at Headquarters to launch these two important planetary missions on schedule.

Work continues to select the proper grain size for pyrotechnics in the Super*Zip band which will separate the Centaur stage from the spacecraft after it leaves Earth orbit bound for Jupiter. Work also continues on radiation hardening chips for the attitude and articulation control subsystem (AACS) and command and data subsystem (CDS) flight computers.

On November 18, the flight unit retropropulsion module (RPM) was delivered to JPL from DFVLR, Federal Republic of Germany. The 400-newton engine and 10-newton thrusters will be delivered in 1984. Currently, the RPM is undergoing proof pressure, leak, and other testing incidental to formal acceptance by the Project.

The spacecraft test and integration schedule has been extended several months, mainly due to late software

See page 2

Sandia

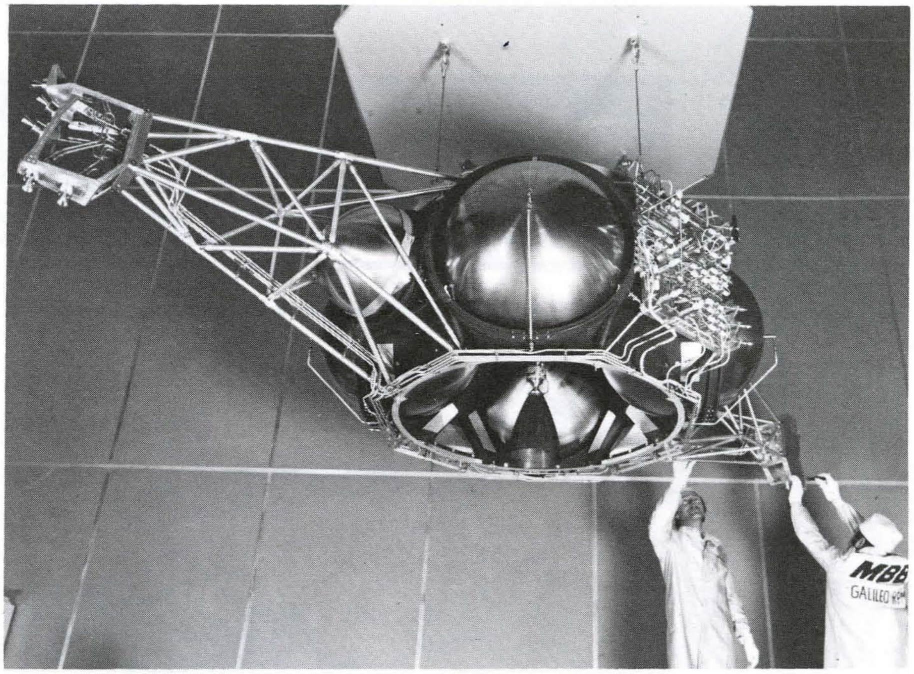
As the Galileo orbiter swings past Jupiter for the first time in August 1988, listening for signals from the atmospheric probe, it will be bombarded by highly energetic particles in a severe radiation environment. If these particles affect the spacecraft's sensitive electronics, changing their electrical responses, the mission could be dealt a major blow.

To assure the orbiter's survival, several steps are being taken to protect its precious cargo, including the use of radiation hardened integrated circuits (ICs) scattered throughout the spacecraft. The design requirement demands that the chips be able to withstand a dose of 150,000 rads (150 krads)* with high reliability, taking into account the effects of radiation exposure both on the first swingby and during the satellite tour phase.

The orbiter's electronics will consist of perhaps 21 microprocessors and 3500 memory chips. Since many of the important chips were not radiation hardened, JPL turned to Sandia National Laboratories in Albuquerque, New Mexico, to develop the necessary radiation hardening processes and chips.

Sandia, operated by Bell Telephone's Western Electric for the U.S. Department of Energy and other federal agencies on a nonprofit basis, plays a major role in national defense and energy. Sandia's Center for Radiation-Hardened Microelectronics (CRM) focusses on creating radiation hard technologies, generating IC designs, producing parts when there is no industrial source, and transferring the designs and technology to private companies. Galileo's needs could not be met by industrial suppliers who deal in large-quantity orders for high-demand parts that do not meet Galileo's radiation-hardening requirements.

"Genetics and microelectronics are probably the two most dynamic technologies today. A generation of technology may be only three to five years old before there are new developments," says CRM's chief Bob Gregory. "We want to maintain our position as the country's leader in developing radiation hardened technologies and making them available to users. The severity of the radiation levels are not much different now than they were in the mid-1960's—what changes is the steady increase in complexity of the integrated circuits."



MBB

Technicians at Messerschmitt-Bölkow-Blohm inspect the retropropulsion module.

As an example, the new random access memory (RAM) chip designed by CRM for Galileo can sense, store, and retrieve 16,384 bits of information, compared to only 1024 bits for the previous generation of radiation hardened RAMs. The new chip contains more than 100,000 transistors and continues to function after one million rads (one megarad) total dose exposure. And its size is only 0.6 × 0.4 centimeters.

As such parts get smaller and smaller, they are affected not only by ionizing radiation but also by upsets due to collisions with energetic particles such as cosmic rays and trapped heavy ions. These events are referred to as Single Event Upsets (SEUs). It was recently determined after a review of Voyager and Pioneer data that there is a significant number of potentially dangerous oxygen and sulfur ions in the Jupiter environment. This environment would cause significant disruption in the orbiter's attitude control (AACS) electronics. Once again, Galileo turned to Sandia to develop replacement parts immune to both ions and ionizing radiation.

Design and development of a new IC requires anywhere from six weeks to two years. "When JPL asked Sandia to design the new chip needed for Galileo's attitude control system, the task involved demanding requirements, small quantities, and a short time scale. We undertook it because it is a critical need of the program," says Gregory. "We consider our work for Galileo very challenging and important. It has high visibility and support at the top levels of Sandia."

Sandia's task, begun in August 1983, is to redesign, produce, and deliver the new parts by September 1984, replacing high-speed bipolar technology with slower but SEU-immune CMOS (complementary metal oxide semiconductor) chips. Design is complete, and chips should be available for testing in mid-May 1984. ■

*A rad is a unit of radiation energy absorption. A chest x-ray dose is about 0.025 rad, while a whole body dose of about 1000 rads is usually fatal to humans.

From the Project Manager

Continued from page 1

deliveries and hardware problems, as well as reassessment of the time required to conduct certain operations based on the operating experience to date. Flight acceptance is now scheduled for early 1985. Even with the change in schedule, we have a comfortable margin for burn-in and the incorporation and checkout of the Single Event Upset fixes before shipment to Florida in January 1986. ■

—John Casani

The container bearing the flight retropropulsion module is unloaded at JPL.

Dust Detection

Continued from page 1

extent, and orbital trajectories of the sub-micron-sized dust particles and to determine if there is indeed a dust wedge.

Jupiter's satellites are continually bombarded by meteoroids and dust particles—both interplanetary material and debris from within the jovian system. By measuring the dust flux near the satellites, much can be learned about the satellites' surface properties in relation to the dust flux. Spatial and temporal variations, as well as directional asymmetries in the dust flux, will give clues to the reasons for albedo (reflectance) variations of the satellites.

As meteroids impact the surface of our moon, surface material flies up and is ejected from the impact crater. A small percentage of this ejecta receives enough velocity from the force of the impact to actually escape from the moon's gravity. Similar ejection processes probably occur on Jupiter's satellites, contributing to the dust environment around the planet. During close encounters with the satellites (less than 1000 kilometers from the surfaces), the dust detector will be able to detect such ejecta particles. From this measurement, scientists can estimate the total meteoritic influx on the satellites.

The dust detector will measure the electrical charge on the larger dust particles entering the instrument. By correlating these measurements with measurements of the flux of high-energy particles, one can study how the dust grains become charged. Measurements of particle velocities will provide information on the frictional interaction with the plasma, while the measured particle mass distribution will give information on the source and transport mechanisms. If the dust particles carry an electrical charge, they may co-rotate with Jupiter's magnetic field. Electrostatic charges on the dust particles are of particular interest. At Saturn, for example, electrostatic levitation is thought to be the cause of the mysterious radial spoke features in the rings, as fine dust particles are elevated above the ring plane by static electricity along the planet's magnetic field lines.

If large, low-density "fluffy" aggregate particles become strongly charged, the electrostatic force can literally blow them apart, creating a swarm of micrometeoroids. A group in Heidelberg has observed these swarms in the Earth's magnetosphere with their HEOS experiment. A similar fragmentation is expected to occur when "fluffy" interplanetary particles enter Jupiter's magnetosphere.

The instrument is a modified version of the impact plasma micrometeorid detector successfully flown on the HEOS-2 satellite. It consists of a multicoincidence detector and associated electronics, and a microprocessor to control the instrument's operation and process the data for telemetry to Earth.

Positively or negatively charged ions entering the sensor are first detected by the charge that they induce when they fly through the entrance grid. This charge signal will only be evaluated if the ion subsequently impacts the impact plasma detector. Dust particles—charged or uncharged—are detected by the plasma produced during the impact on the gold target of the sensor. After separation by an electrical field, the ions and electrons of the plasma are accumulated by charge-sensitive amplifiers, thus delivering two coinciding pulses of opposite polarity. The pulse height, or total charge, is a function of the particle mass times velocity. The rise time of the pulses depends only on the particle's speed. From both the pulse height and the rise times, the mass and impact speed of the dust particle can be derived. Redundancy in the instrument increases the accuracy of the measurements.

The instrument sensor weighs 2.3 kilograms and requires 0.3 W. The electronics weigh 1.8 kilograms and require 1.5 W. The sensitive area of the sensor is 1000 cm^2, and the unobscured field of view is 140°. The instrument will be able to detect particles with mass from 10^{-16} g to 10^{-6} g and charges from 10^{-14} Coulomb to 10^{-12} Cb (positive) or 10^{-10} Cb (negative). It will be able to detect as many as 100 impacts per second.

The principal investigator is Eberhard Grün of the Max Planck Institut für Kernphysik (MPIK) in Heidelberg, Federal Republic of Germany. He is aided by an international team of six co-investigators. The instrument was designed and built by the Space Electronics Group at MPIK with the help of outside contractors ARGE PEES, Wald Michelbach, and WFG Fischer GmbH, Stuttgart. ■

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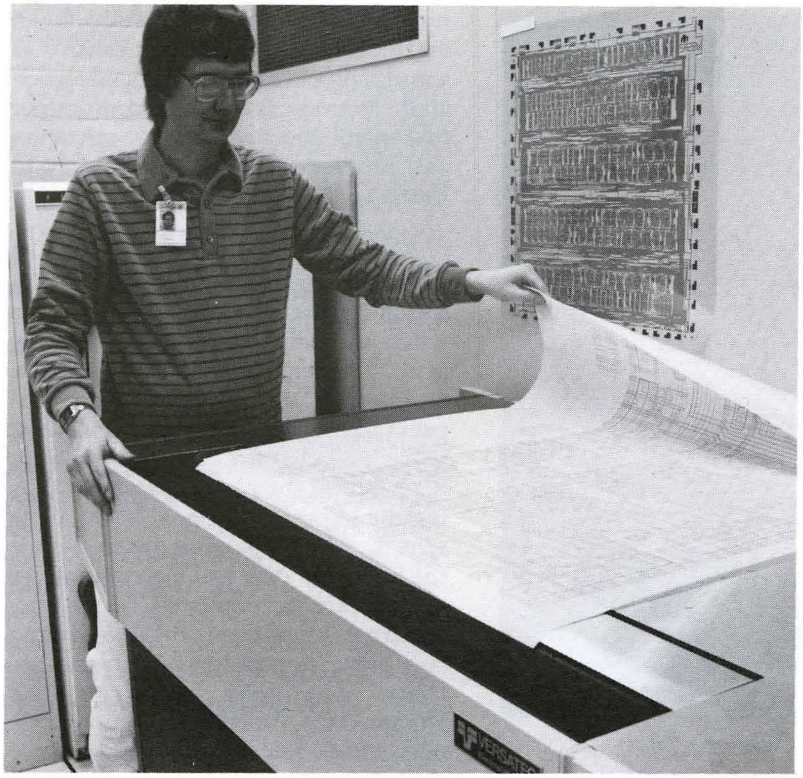


Sandia

Mask layers are plotted by computer for final design checking.

Sandia

A quartz "boat" of silicon wafers is loaded into a furnace.

Semiconductors

Fifty years ago a project such as Galileo belonged to the realm of "speculative fiction"—it couldn't be done. Perhaps no advance in technology has had more impact on what we can do in space than has the field of microelectronics—the miniaturization of electronic circuits, especially for use in computers.

The development of the transistor in 1948 provided a small, low-power device to control electrical signals for digital systems. Transistors are made of solid materials such as silicon or germanium whose electrical properties lie somewhere between conductors and insulators: they are *semi*conductors. Exploiting the characteristics of the semiconductors, such as the positive (*p*) and negative (*n*) regions that could be created within them, led to the development of integrated circuits (ICs)—circuits with many transistors, resistors, and diodes on a single "chip" of semiconducting material.

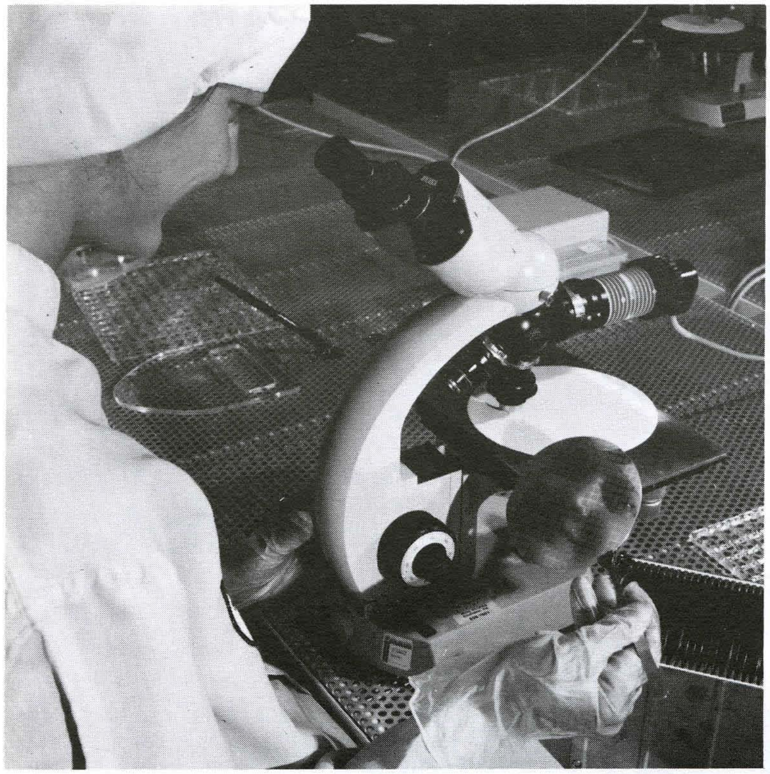
In large scale ICs, tens of thousands of transistors and their interconnections are manufactured simultaneously on a silicon chip perhaps one-quarter of an inch square and 25 mils thick (a mil is a thousandth of an inch). The size of the features on the circuit are decreasing: in 1975, the structural features were about 10 microns; today, they approach the 2-micron size. (A human hair is about 75 to 100 microns in diameter.) The decrease in feature size allows an increase in the number of features, such as transistors, that can be packed onto a single chip, thus increasing the complexity of the functions that can be performed.

Semiconductor devices are made by introducing impurities into pure silicon to affect the electrical properties, a process called doping. Doping with an element that results in an extra electron in the atomic structure gives an *n*-type semiconductor (for the negative charge of the electron). Doping with an element that creates a deficiency of one electron, or a hole in the lattice of the silicon's atomic structure, gives a *p*-type semiconductor (the hole has a positive charge and can carry an electrical current). A semiconductor may have "wells" of either type, or both, depending on its functions.

Semiconductors to be used in space run the risk of radiation damage, in which high-energy particles may alter the atomic structure by adding an electron or creating a hole. Galileo's journey into Jupiter's sizzling radiation belts require that its computer chips be radiation hardened—able to perform even after a radiation dosage of 1.5×10^5 rads.

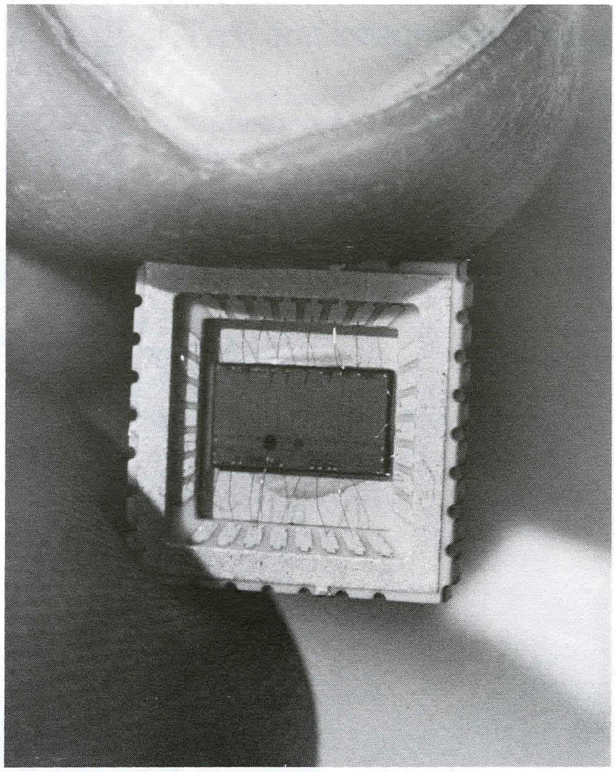
Radiation hardness is built into the chips in several ways: chip designs and higher voltages strive to make circuit operations relatively insensitive to radiation-induced shifts in operating parameters such as threshold voltages; synchronous circuits, driven by a master clock producing a constant stream of control pulses, are preferred over asynchronous circuits since they are less affected by extraneous signals and processing variations; leakage paths caused by ionizing radiation are limited by placing highly conductive guard bands around the oppositely charged transistors. In the actual processing steps, extreme cleanliness, thin oxides, and reduced processing temperatures are radiation hardening techniques.

An IC is complex in both the topography of its surface and its internal structure. It has a three-dimensional architecture made up of many layers of detailed patterns. Computer-aided design (CAD) is an important tool in designing a new IC. A library of standard "cells" is available for various functions, and these cells are modified, layered, and hooked together as needed for a specific function. Computer analyses are used to troubleshoot during the design process to minimize later production and performance problems. Designers maintain close contact with both the engineers who



Sandia

A wafer containing many die is inspected by a processing science technologist.



Sandia

A technician holds a packaged semiconductor chip.

will use the chip and the processors who will manufacture it. The design phase may take several work-years.

Once the design is completed and approved, a set of plates, called photomasks, are produced. These are the masters for producing the chips. A single layer of a circuit is produced many times on the mask in a "step-and-repeat" pattern. Currently, photolithography is used to create the masks with high-resolution cameras, but new technology for electron beam lithography will allow the pattern to be printed on the mask directly from the computer. The chips manufactured by Sandia for Galileo's attitude control system require nine masks.

Chip production starts with the growth of a single large crystal of silicon, perhaps three to four inches in diameter and several feet long. The crystal is cut into wafers, typically two to four inches in diameter and half a millimeter thick, and the wafers are polished. An oxide layer is then grown on the surface of the silicon wafer as an insulator and as a mask for the doping processes. The microelectronic circuit is built up layer by layer, using the masks in a photoengraving technique. Perfect alignment is required as each layer is added. The doping occurs in this stage. The final masks include a metal mask to form the interconnections between the circuits and the bonding pads for wires which will connect the finished circuit to other circuits. After extensive testing to weed out defective circuits, the wafer is sawed into dice, or chips. The chips are mounted within a cavity in a ceramic package and fine wire leads are connected from the bonding pads on the dice to the electrodes of the package. The packages are then sealed and readied for final testing.

Galileo is using complementary metal-oxide semiconductors (CMOSs). CMOS ICs have both *p*-channel and *n*-channel MOS transistors. These semiconductors cut power consumption, an important point for a spacecraft that must generate and regulate its own power. ■

Special thanks to . . .
E. Graham (N5HH), B. Gregory, T. Gavin, L. Wright

National Aeronautics and
Space Administration
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

JPL D-602-9

WWWWWH*

**(Who, What, When, Where, Why, and How)*

Q: How do we know when to launch Galileo from the Earth so that it not only reaches Jupiter at the right time, but also encounters the Galilean satellites properly?

A: Celestial mechanics deal with how heavenly bodies move and the complexities involved with flying to the planets and encountering them at certain times and places in space. Galileo's Science and Mission Design Team has the challenging task of calculating how and when to launch Galileo so that it satisfies the many scientific objectives. Currently, there are three possible satellite tours. As the launch date gets closer, the specific tour to be flown will be selected. ■

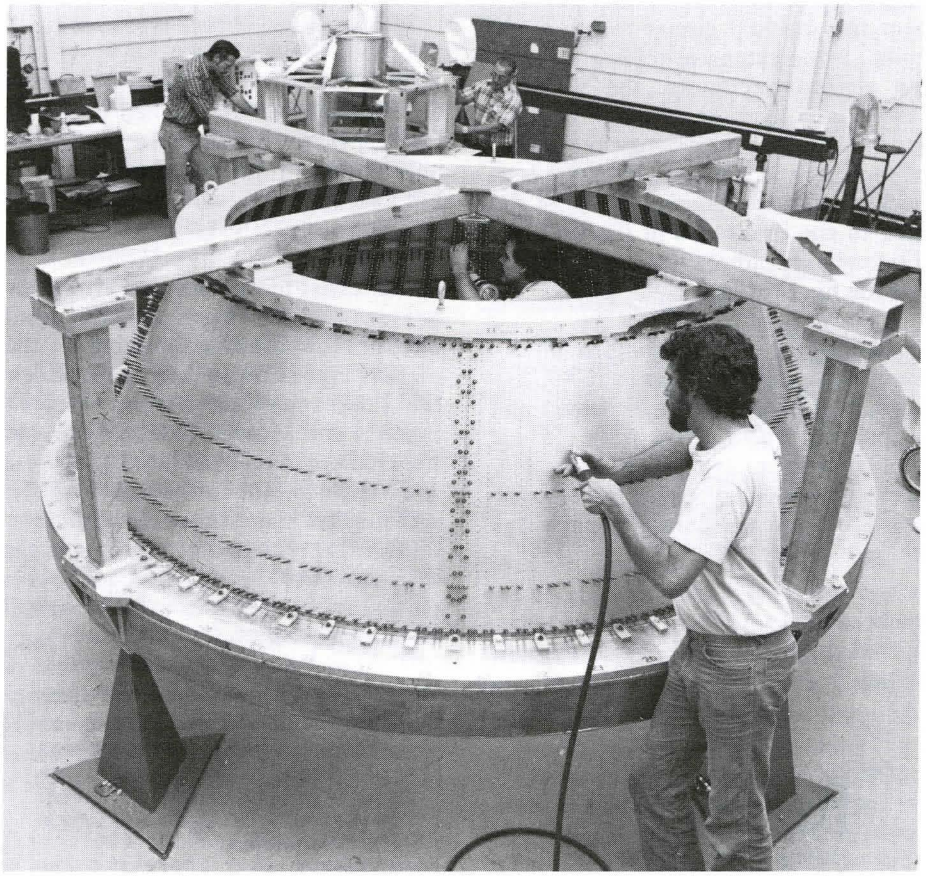
J. Harris

Note: In the October 1983 issue's article on Single Event Upsets, please note that by themselves, Io's volcanoes do not impart enough velocity to particles to cause them to escape from the satellite.

B. G. Lee

Editor .... Anita Sohus
Typesetting & Layout .... JPL Graphic Services
Printing .... JPL Printing Services
Galileo Project Information Coordinator .... Joel Harris

JPL's machine shops have fabricated many Galileo parts.



Spun bus (rear) and Centaur adapter ring were fabricated by JPL's Fabrication Engineering and Services Section.

Meet the Team

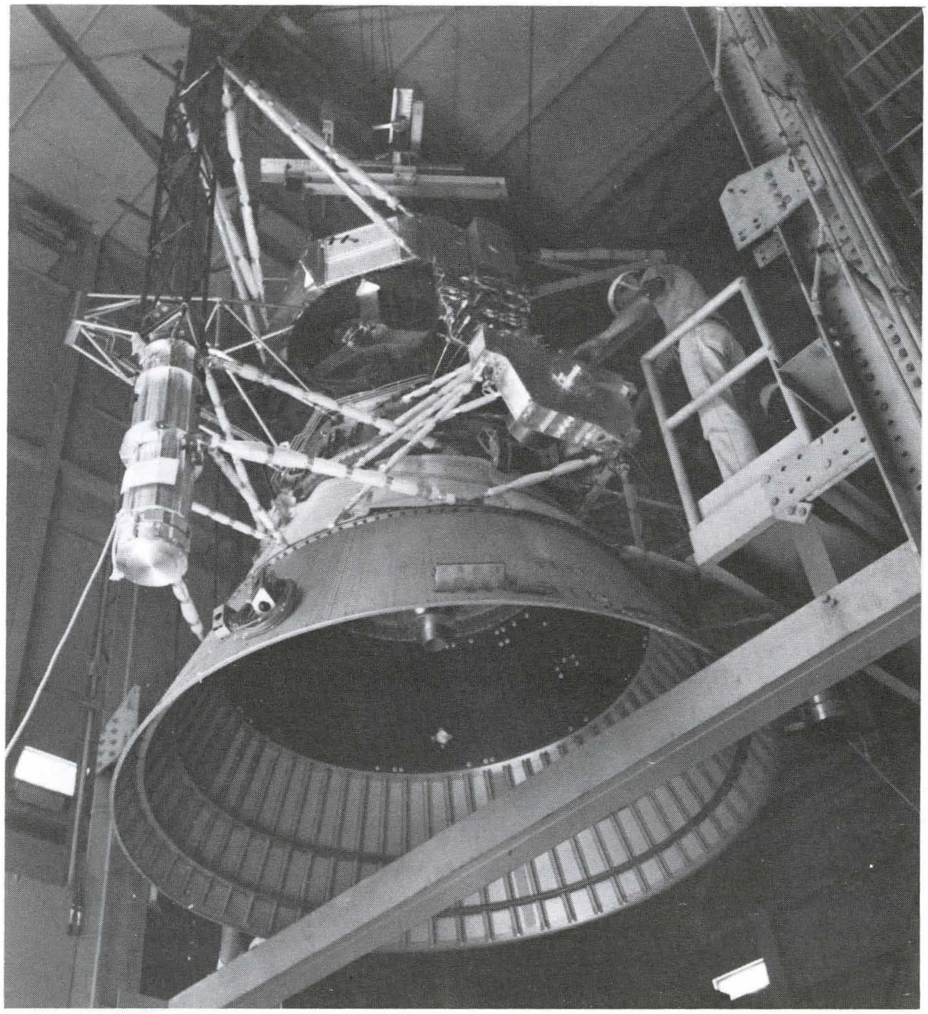
Matt Landano

The Galileo Project can be glad that a young native of St. Louis, Missouri heeded Horace Greeley's advice to "Go west, young man," for Matt Landano has made valuable contributions to the design of the Galileo spacecraft.

Matt joined JPL in 1969 and gave four years to the Viking spacecraft design before turning his attention to Voyager. In 1978 he became supervisor of the Outer Planets Spacecraft Design Group, and in the fall of 1982 he was appointed Galileo's third Spacecraft System Engineer, following Ron Draper and Chris Jones.

"It has been very challenging to develop a spacecraft design for such an ambitious mission and to keep the design on track despite all the redirections. I feel confident we will have a spacecraft that meets the mission requirements," Matt says. "We have a unique spacecraft configuration that has never been flown before: dual spin with long flexible booms, nine science instruments and an entry probe. Sophisticated attitude control is necessary for pointing the science instruments and antennas to provide the high data return at large distances. There have been a number of new hardware and software developments, particularly in the attitude control and data system designs. It's been exciting to be involved with such an advanced design spacecraft."

Matt's team is now actively supporting the system design verification activities as both the Development Test Model and the flight spacecraft undergo integration and test. They continue to be deeply involved in the single



Development Test Model is hoisted into place in the Static Test Tower.

Meet the Team *Continued from page 6*

event upset (SEU) effort and in the development of flight software, especially in the areas of sequencing and fault protection, both critical to the proper, autonomous functioning of the spacecraft far from Earth.

Like a lot of other people, Matt had great interest in space in the 1960's, but never suspected where this might lead him. After receiving B.S. and M.S. degrees in electrical engineering from California State University at Los Angeles, Matt did missile work at General Dynamics and McDonnell-Douglas until he joined JPL.

Matt, his wife Angeline, and teen-aged daughters Lisa and Karen live in Glendale. They are active in supporting hospital functions and their church, and enjoy going to the mountains and deserts. The whole family has taken up skiing. At home, Matt likes to garden, and avidly reads mythology, particularly Greek and Roman. ■

Static Test

The Development Test Model of the Galileo spacecraft has completed 14 weeks of static test as part of the structural validation activities. The tests are required of any structures that will fly in the Space Shuttle. There are 26 tests in this series, conducted in JPL's Static Test Tower.

For these tests, engineers first calculate the maximum accelerational loads (G's) that may occur during Shuttle launch. These loads are then simulated in the DTM structure with hydraulic rams. Resulting stresses within the structure are measured by strain gages. A microcomputer control system is programmed to monitor the strain gages and protect the structure from excessive loads. The loads induced in test are 20 percent greater than expected to occur during launch. Data from the tests will be used to correlate predictions made in mathematical analysis of the structure during the design process.

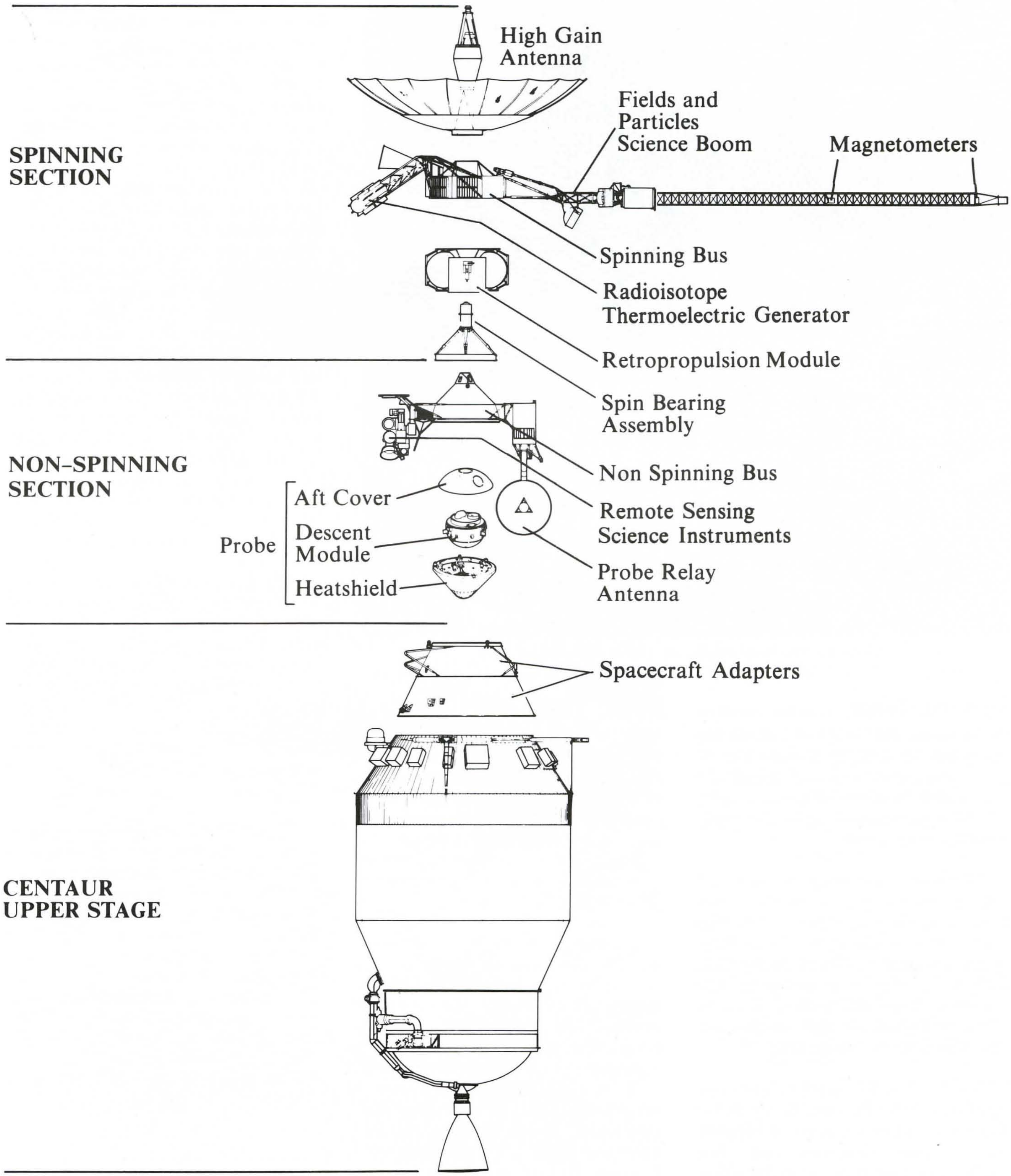
Test and Integration Status

As of late November 1983, all flight hardware for the Galileo orbiter had been tested with the exception of the X/S downconverter, the star scanner ceramic tubes, and the flight radioisotope thermoelectric generators. Major updating will be required for fuses, random access memory (RAM) chips, microprocessors, and radiation hardening. Phased software deliveries have allowed subsystem integration to proceed to date, and major software deliveries will occur in January 1984 for the attitude and articulation control subsystem (AACS) and April 1984 for the command and data subsystem (CDS) and additional AACS. Electrical integration of subsystems was completed in October with significant liens due to late hardware and software deliveries. All flight subsystems have been integrated except the retropropulsion module (RPM), antenna system (SXA), and spin bearing assembly (SBA). Additional work is required to complete the electrical integration of the AACS and CDS. All other subsystems have performed as required.

The first phase of spacecraft integration—electrical and functional compatibility between the orbiter and probe systems—occurred in September 1983. Major tasks included integration of 1) the relay radio hardware into the orbiter, 2) the probe and the orbiter, and 3) the mission telemetry system (MTS) and the probe flight operation equipment (PFOE), as well as a probe end-to-end data test.

Updated orbiter and probe hardware is scheduled to be delivered to JPL's Spacecraft Assembly Facility (SAF) starting January 16, 1984. Spacecraft integration will resume in February 1984 when the orbiter and probe are electrically connected. The first phase of system test will take place this spring, followed by environmental tests this summer, and the second phase of system tests in the fall. The spacecraft is scheduled to be capable of being committed to flight by March 1, 1985. ■

Bill Layman is the Galileo project engineer, Frank Tillman is the environmental test director, and Jim Staats is the static test director, all of the Applied Mechanics Division. ■



Exploded view of Galileo spacecraft and upper stage.

The Galileo Messenger

1625-101, Issue 10 April 1984

From the Project Manager

The first phase of orbiter integration testing was completed in November 1983. This test series, designed to establish electrical interface compatibility, was conducted using flight electronics mounted to mock-up structure. On December 1, the electronics and cabling were removed from the mockup structure and returned to the laboratories for necessary rework including replacement of component parts and modifications identified during testing. On January 16, 1984, flight structure was delivered to the Spacecraft Assembly Facility (SAF) at JPL, and modified cabling and electronics were redelivered. Delivery of the electronic subsystems will be phased between January and April 1984. Four orbiter instruments will also be retrofitted, and the orbiter's command and data system (CDS) is undergoing redesign of the memory "keep alive" circuits.

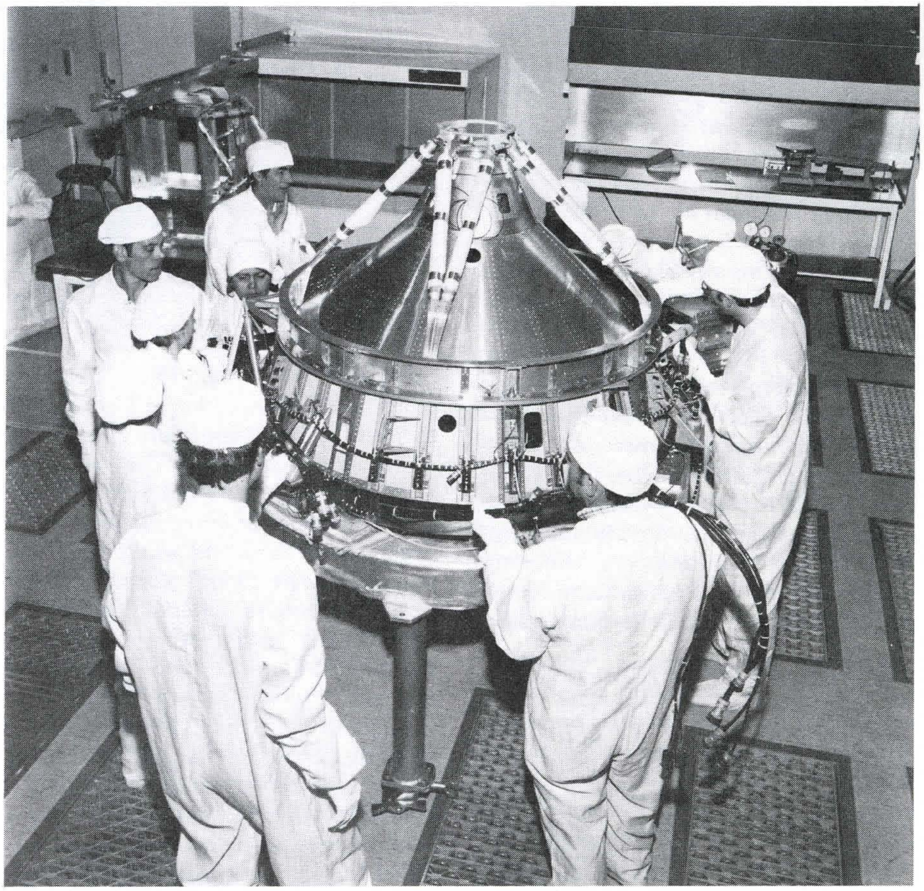
The flight probe was delivered to JPL from Hughes Aircraft Company in February for integration with the orbiter and ground systems. This probe contains engineering models of four of its six instruments, as well as the data and command processor (DCP). These will be retrofitted in June before environmental testing begins.

Prevention of single event upsets (SEUs) in the spacecraft computers due to heavy ions and cosmic rays continues to be the major concern of the Project. Two solutions are being pursued in parallel until sufficient confidence is attained in one to allow the other to be dropped. One solution involves replacing semiconductors sensitive to SEUs with functionally equivalent radiation-hardened parts. The second solution involves replacing the microprocessor used in the Attitude and Articulation Control Subsystem (AACS), with a new processor built to be insensitive to SEUs.

The design of the replacement parts at Sandia National Laboratories is complete (about one month ahead of schedule), mask preparation is in process, and wafer production has begun. Verification of this solution will be possible when the new parts are available for substitution into the hardware and hardware performance can be verified, probably in June 1984.

The second solution uses an adaptation of the Radiation Hardened Emulating Computer (RHEC), developed by the Air Force, as the replacement processor. The design of the processor is essentially complete, and design analysis and layout of the processor board is in progress. System timing and interface compatibility will be verified by testing an operating prototype of the new processor and its required circuitry in the AACS. □

J.R. Casani



White-robed technicians in a clean room install the electrical cabling harness on the flight structure of the orbiter's despun section.

RTGs

Nuclear-powered spacecraft have orbited the Earth and probed deep space for over twenty years. Nuclear power supplies a constant source of electricity over a long lifetime with high reliability, insensitivity to the chilling cold of the outer reaches, and virtual invulnerability to high radiation fields such as Earth's Van Allen belts and Jupiter's sizzling magnetosphere.

The Galileo mission will be the 24th U.S. space mission since 1961 to be powered partially or totally by nuclear power sources. These missions, for both the U.S. military and NASA, have included Earth-orbiting weather, communications, and navigational

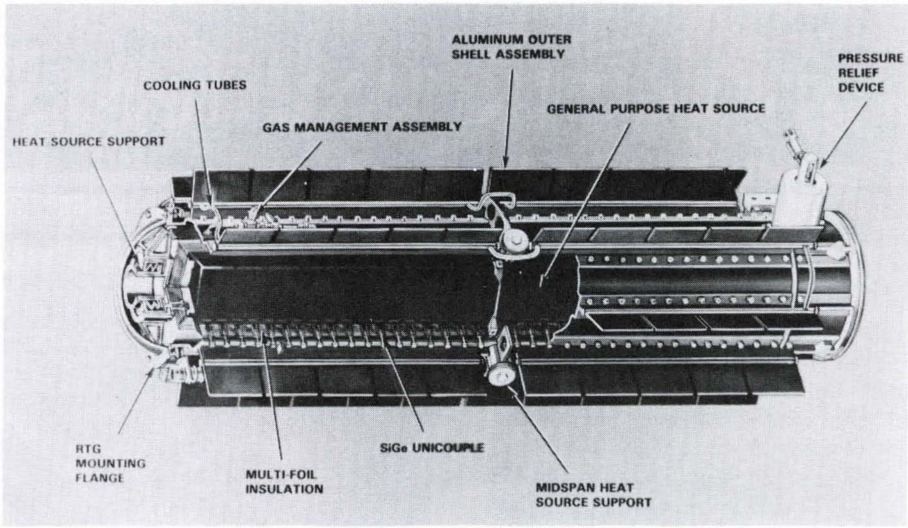
satellites, as well as the Apollo, Pioneer, Viking, and Voyager space programs. The Soviet Union uses nuclear-powered spacecraft as well. The Galileo orbiter will carry two 285-watt (electrical)* general purpose heat source (GPHS) radioisotope thermoelectric generators (RTGs) while approximately 112 one-watt (thermal) radioisotope heater units (RHUs) will warm scientific instruments onboard both the orbiter and the probe.

An RTG basically consists of two parts: a source of heat and a system for converting the heat to electricity. The heat source contains a radioisotope, such as plutonium-238, that becomes physically hot from its own radioactive decay. This heat is converted to electricity by a thermoelectric converter which uses the Seebeck effect, a basic principle of thermoelectricity discovered in 1822. An electromotive force, or voltage, is produced from the diffusion of electrons across the junction of two different materials (e.g., metals or semiconductors) that have been joined together to form a circuit when the junctions are at different temperatures. Junctions of different metal wires are used to measure temperatures and are called thermocouples.

Doping semiconductor materials such as silicon-germanium with small amounts of impurities such as boron or phosphorus produces an excess or deficiency of electrons, and therefore makes the semiconductor a more efficient power converter than metals. The joining of these thermoelectric materials with hot radioisotopes produces a reliable source of power with no moving parts. The temperature difference between the hot and cold junctions in these thermocouples is about 700 Kelvin.

Nuclear safety is a major factor in the design of these power sources. Plutonium-238 decays primarily by emitting alpha particles, which are completely absorbed in the heat source to produce heat; thus, no special radiation shielding is necessary to absorb these particles. (Moderate neutron and gamma-ray fields exist external to the RTG, requiring isolation of the RTGs from the rest of the spacecraft to prevent interference with the scientific measurements. Therefore, each RTG will be mounted at the end of a 5-meter boom.) The principal safety objective

*The thermal power at the beginning of the mission will be 4,410 W per generator.



Two nuclear generators will power the Galileo spacecraft. Each is about 45 inches long, 16 inches in diameter, and weighs 122 pounds.

connected with the use of plutonium-238 is to keep it contained to prevent contamination of the surrounding environment. The half-life of ^{238}Pu is about 87.8 years, and nuclear-powered Earth-orbiting satellites have been placed in orbits where they will not reenter the Earth's atmosphere until the radioactive material has decayed to harmless levels. After the Soviet Cosmos 954 satellite (which carried a nuclear reactor) fell to Earth over Canada in 1978, the U.N. established a working group on the use of nuclear power sources in outer space which concluded that nuclear power sources "can be used safely in outer space provided that all necessary safety requirements are met."†

Each 122-pound GPHS RTG contains approximately 24 pounds of plutonium dioxide fuel, pressed into 72 solid ceramic-like cylindrical 1 inch by 1 inch pellets.

Each heat source consists of 18 separate modules, each of which multiply encases four Pu-238 pellets. The modules are designed to survive under a range of postulated accidents: launch vehicle explosion or fire, reentry into the atmosphere followed by land or water impact, and post-impact situations. Graphitic outer coverings provide protection against the structural, thermal, and ablative environments of a potential reentry; additional graphitic components provide impact protection, and iridium cladding of the actual fuel cells provides post-impact containment. The GPHS RTGs are designed to release the 18 modules individually in the event of an accidental reentry.

†*United Nations Committee on the Peaceful Uses of Outer Space, "Report of the Working Group on the Use of Nuclear Power Sources in Outer Space on the Work of its Third Session," Annex II to "Report of the Scientific and Technical Subcommittee on the Work of its Eighteenth Session," U.N. document A/AC.105/287, 13 February 1981.*

The RTGs for the Galileo project are identical to those to be used for the International Solar Polar Mission (ISPM). The current development program includes RTGs for both Galileo and ISPM, as well as a spare.

The Office of Special Nuclear Projects of the U.S. Department of Energy (DOE) is responsible for the government RTG program, while the General Electric Company at Valley Forge, Pennsylvania, is the system contractor responsible for the design and development of the electrical converter and heat source. The fuel is fabricated and encapsulated in the iridium cladding at DOE's Savannah River Plant, South Carolina, and shipped to DOE's Mound Plant in Miamisburg, Ohio, where the pellets are loaded into the graphite modules. Here, the heat source modules are also installed into the generators and qualification and flight acceptance tests are conducted. Oak Ridge National Laboratory, Tennessee, provides graphite insulation and iridium for the post-impact containment structure. Safety testing is conducted at Los Alamos National Laboratory, New Mexico, with independent reliability and quality assurance support provided by Sandia National Laboratories, Albuquerque,

New Mexico. Independent safety and technical support is supplied by the Applied Physics Laboratory, NUS Corporation, and Fairchild Industries.

The thermoelectric converter for the qualification unit has been fueled at Mound, and is currently undergoing testing. The flight thermoelectric converters for Galileo have been fabricated but will not be fueled until later. The RTGs will be stored until shipment to Kennedy Space Center, Florida, where they will be installed on the spacecraft and tested. They will then be removed and stored until final installation on the spacecraft in the Shuttle payload bay on the launch pad several days before launch in May 1986. □

Thanks to G. L. Bennett, DOE, and R. W. Campbell, JPL, for source material and review comments.

Meet the Team

Wolfgang Hagenest

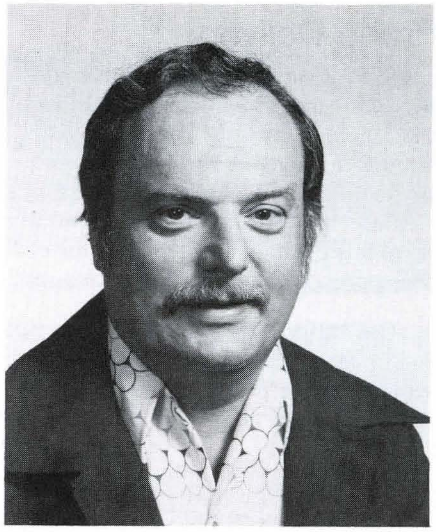
Wolfgang Hagenest is the Project Manager for Galileo at *Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt e.V.* (DFVLR) an agency for the Federal Ministry for Research and Technology of the Federal Republic of Germany. He has been associated with Galileo since its inception, primarily managing the development of the retropropulsion module (RPM), which was built by Messerschmitt-Bölkow-Blohm (MBB) in Ottobrunn, Federal Republic of Germany.

After graduating from the Technical University in Aachen, Wolfgang spent four years in Egypt working on aircraft aerodynamics. Returning to Köln, he worked on a number of national and international spacecraft projects at DFVLR's predecessor. In 1969 he became a spacecraft system engineer for launch vehicle interfaces and launch operations for Helios, a two-spacecraft mission to study the Sun. In conjunction with Helios, he and his family spent a year in 1969-70 in the U.S. at NASA's Goddard Space Flight Center, Lewis Research Center, and Kennedy Space Center. Because of his strong contacts from Helios and Galileo, he is often consulted at DFVLR on issues of international relations.

"The triangular relationship among DFVLR, JPL, and MBB has presented challenges in considering the interests of each," he notes.

A chemist's son, Wolfgang was born in Köln and now lives with his family in Meckenheim, a suburb of Bonn. His daughter is studying in Munich to be a physical therapist, and his son plans to study chemistry at the university after graduating this year from the gymnasium (equivalent to high school and two years of college in the U.S.). Wolfgang's hobbies include travel, photography, railroad models, and classical music, especially German composers. In recent years he and his wife Uta have taken up hiking, and enjoy the hut systems in Switzerland. A big thrill last year was hiking on a glacier. In 1986, they plan to celebrate their 25th wedding anniversary by hiking near Zermatt, where they spent their honeymoon. □

Meet the Team



Don Kindt

Don Kindt remembers the days when an entire project team could meet in one room. Today's complex missions require thousands of people to design, build, and fly a mission. Don joined the Galileo project in 1980 as the Probe Interface Manager to coordinate the various organizations involved in the probe mission. The design and testing of the interface between the probe and orbiter is a primary function of his effort. He has been associated with Galileo since the study phases, and supported Ames Research Center (ARC) during the source evaluation period, which ultimately led to the selection of a contractor to build the probe.

Natives of Milwaukee, Don and his wife Joan traveled West after he received his MSEE degree from the University of Wisconsin. His first job at JPL involved testing the radio inertial guidance for the Jupiter missile, followed by work on the Sergeant missile. He later worked on power systems for the Ranger spacecraft and was responsible for the Ranger television system that took the first closeup pictures of the moon. As supervisor of the launch vehicle (and payload) integration group, he was responsible for the interface design between the Viking orbiters and landers. This experience led to his current role.

"Coordinating the interface between several organizations is like being a combination of interpreter, referee, and diplomat," Don says. "Sometimes you have to represent the non-JPL organizations to the point that the JPL people involved want to check your JPL badge."

Don likes to travel, but most of it lately has been job-related, with many trips to NASA/Ames Research Center near San Jose, CA, where the probe was developed; to Hughes Aircraft Company, El Segundo, CA, where it was built; and to New Mexico, where it was tested in a realistic drop from a high-altitude balloon.

The Kindts have raised three children in their Glendale home, and now Don has more time to play with his shiny red '67 Mustang. □

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Galileo Project Information Coordinator .... Joel Harris

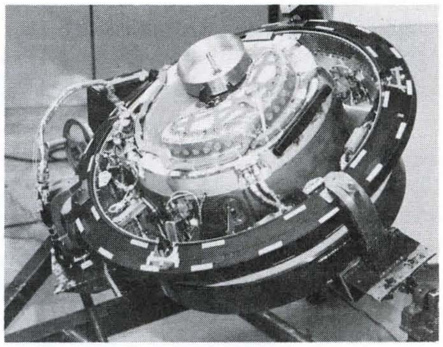
Probe Delivery

"The Galileo mission could be a Rosetta stone for unlocking the origin of the universe," says Nick Vojvodich, deputy manager for the Galileo probe project at NASA/Ames Research Center. "In a five-hour journey, we will learn more (about Jupiter) than have all the spacecraft that have preceded us."

The 742-pound probe will hitch a ride to Jupiter on the Galileo orbiter, which will target the probe and release it 150 days before the atmospheric entry date.

In August 1988, the acorn-shaped probe will plunge into Jupiter's clouds at nearly 100,000 miles an hour — the fastest atmospheric entry speed of any man-made object at any heavenly body. Flying overhead, the orbiter may be able to photograph the probe's meteoric trail through the clouds. At Mach 1, a parachute will deploy, and within seconds the probe will slow to about 2000 miles an hour, losing about half its mass as the heat shield burns away from the friction of the entry. The probe will not be able to communicate through the sheet of ionized gases surrounding it at entry, so the probe will store its deceleration information until the worst of the entry buffeting is over.

Spinning slowly on its parachute lines, the probe will begin to sample and measure the alien atmosphere — shining light beams into it, sucking small samples into its chambers, and recording the temperature and pressure. Its tiny transmitter will relay data to the mother ship passing overhead, where the data will be recorded for later transmission to Earth.



The instrumented descent module nests inside the aeroshell (the aft cover has been removed). The transmitter and main parachute pack are fixed on the shelf above the instruments.

About one hour after the probe dives into the clouds, the orbiter must change its orientation to begin its own mission. The probe will slowly die, its transmission weakened by the thick, moist atmosphere, and its body destroyed by the increasing temperature and pressure 130 kilometers below the cloud tops.

Probe spacecraft manager William Butterworth checks the heatshield before the probe enters a thermal-vacuum chamber for testing at Hughes Aircraft Company.

Project officials described the probe mission and presented the flight hardware for inspection on February 9 at Hughes Aircraft Company, El Segundo, CA as the probe was readied for delivery to the Jet Propulsion Laboratory for integration with the orbiter.

Joel Sperans, Galileo Probe Project Manager at Ames, noted that the probe's descent module is a miniaturized atmospheric sciences laboratory. Special challenges in the development of the probe included the deployment of a parachute behind a blunt body at transsonic speeds, the transmission of the signal through a difficult atmosphere, and the intense radiation at Jupiter.

"We have electrically connected the probe and orbiter and are checking out the equipment that will process the probe's data when it is received at Earth," reports Don Kindt, the probe integration manager at JPL.

The orbiter and probe will undergo environmental testing this summer at JPL, and will be shipped to Kennedy Space Center in January 1986 in preparation for their May 1986 launch date. □

NASA
National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

JPL D-602-10

The Galileo Messenger

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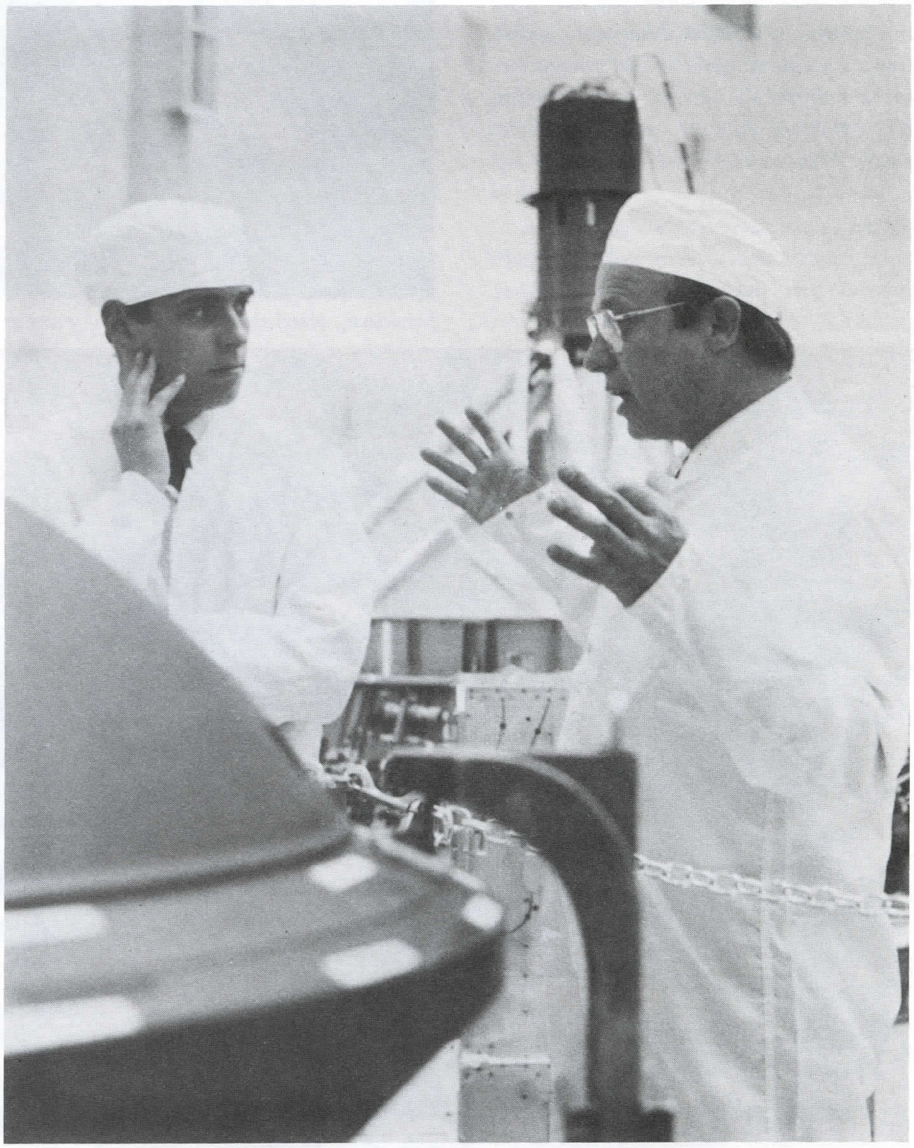
From the Project Manager

The flight spacecraft has completed subsystem and probe integration as well as the first phase of system testing. In August, the flight hardware was moved to JPL's Environmental Laboratory in preparation for vibration testing. Other tests will include baseline, acoustics, radio frequency interference, pyro shock, Centaur separation, and spun/despun release nut tests. The mechanical buildup of the spacecraft in the launch configuration for these tests has proved to be a challenging task indeed.

There has been good progress in the solution to the single event upset problem. The first of the radiation hardened replacement chips for the attitude and articulation control (AACS) processor work perfectly. We owe a big thanks to chip designers Al Giddings, Keith Treece, and Frank Hewlett from Sandia National Laboratories. We have high confidence that the spacecraft's computers will survive dosages of heavy ions and cosmic rays in Jupiter's severe radiation environment.

The random-access memory (RAM) problems affecting the command and data subsystem (CDS), attitude and articulation control subsystem (AACS), and the science instruments have been corrected and the retrofitting of the flight hardware with radiation-hardened screened RAMs is proceeding satisfactorily. The CDS board problems have been fixed and assembly of the new memories will start soon. The AACS rebuild to accommodate the single event upset (SEU) fix is also proceeding very well.



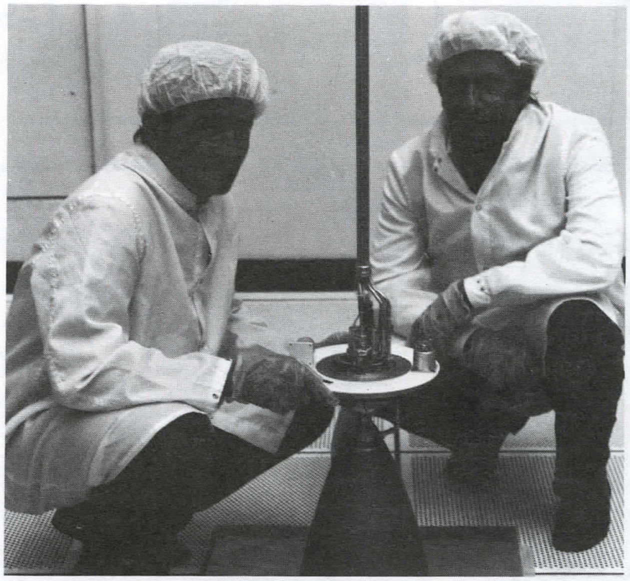
Amid the flight hardware stationed on the floor of JPL's Spacecraft Assembly Facility clean room, Galileo Project Manager John Casani emphasizes a point to England's Prince Andrew.

Earlier this summer, the 400-newton main engine and 10-newton thrusters were mechanically and electrically integrated onto the retropropulsion module (RPM).

Hughes has delivered most of the probe flight equipment, including the deceleration module; the descent module structure, harness, power and communications; all ground support equipment; and the relay radio receivers and antenna. The flight unit of the data command processor will be delivered in December 1984, while the pyro system will be delivered in November. Meanwhile, all of the probe's science instruments have been redelivered, except for the neutral mass spectrometer, which is undergoing changes at Goddard Space Flight Center.

The Centaur development is proceeding well, and a full scale structural model is undergoing test at General Dynamics Convair in San Diego.

–J. R. Casani



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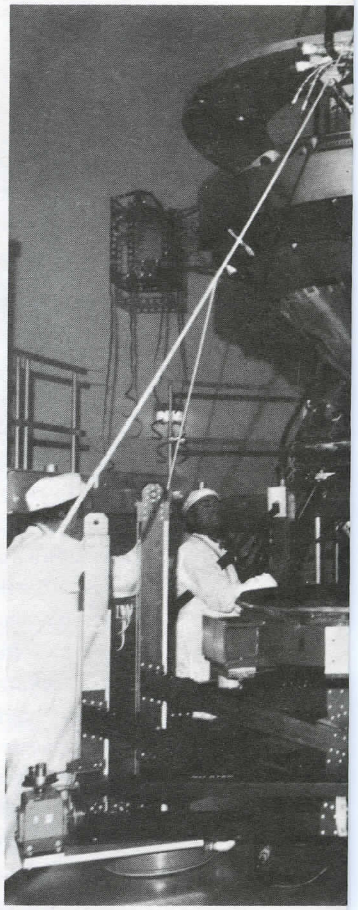

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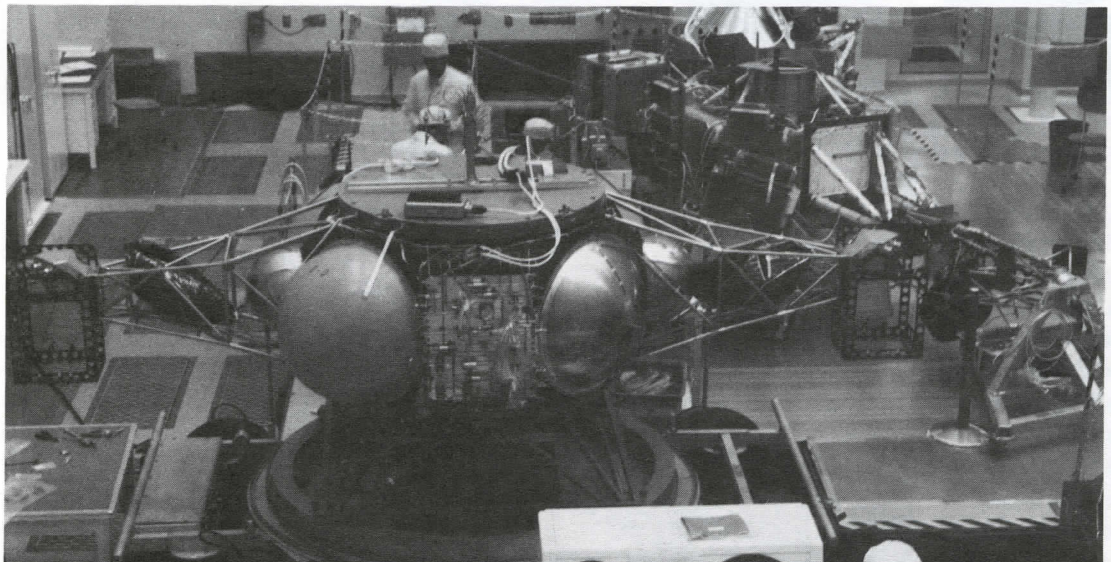

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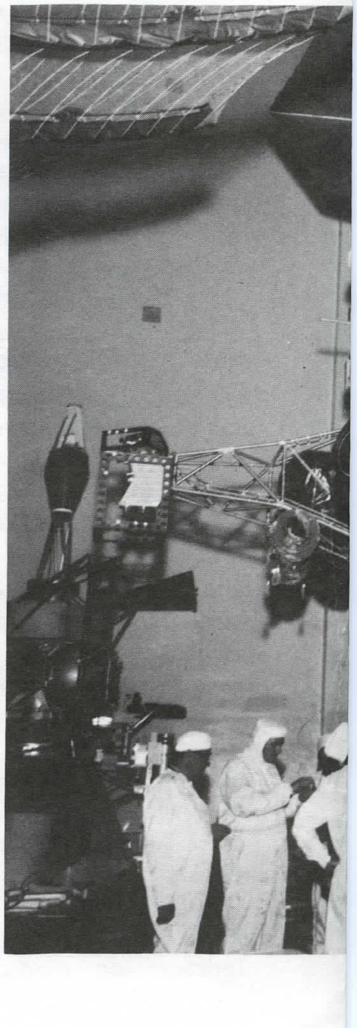

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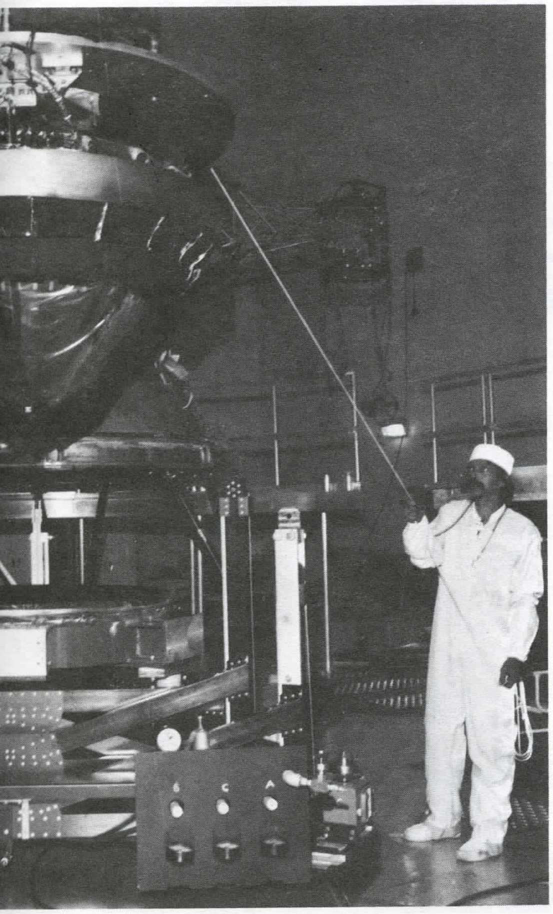

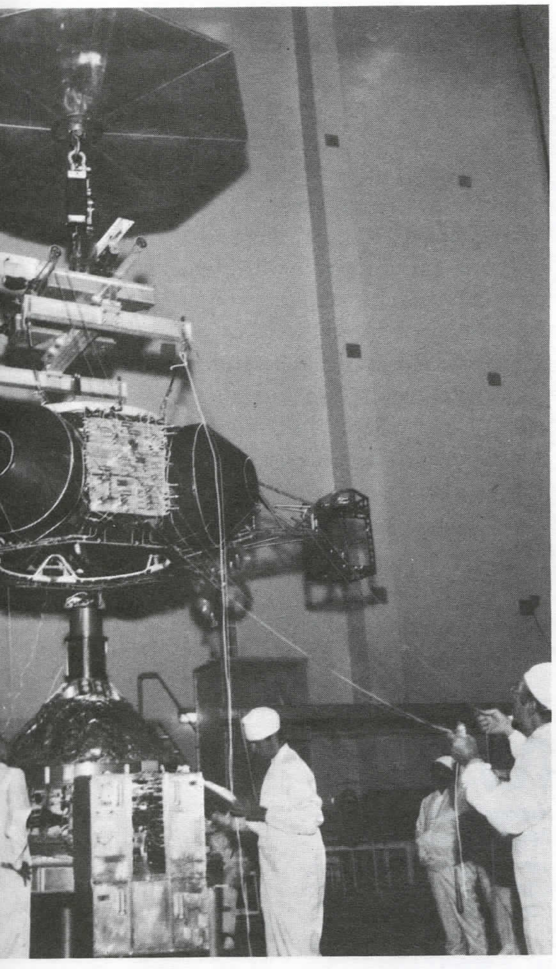

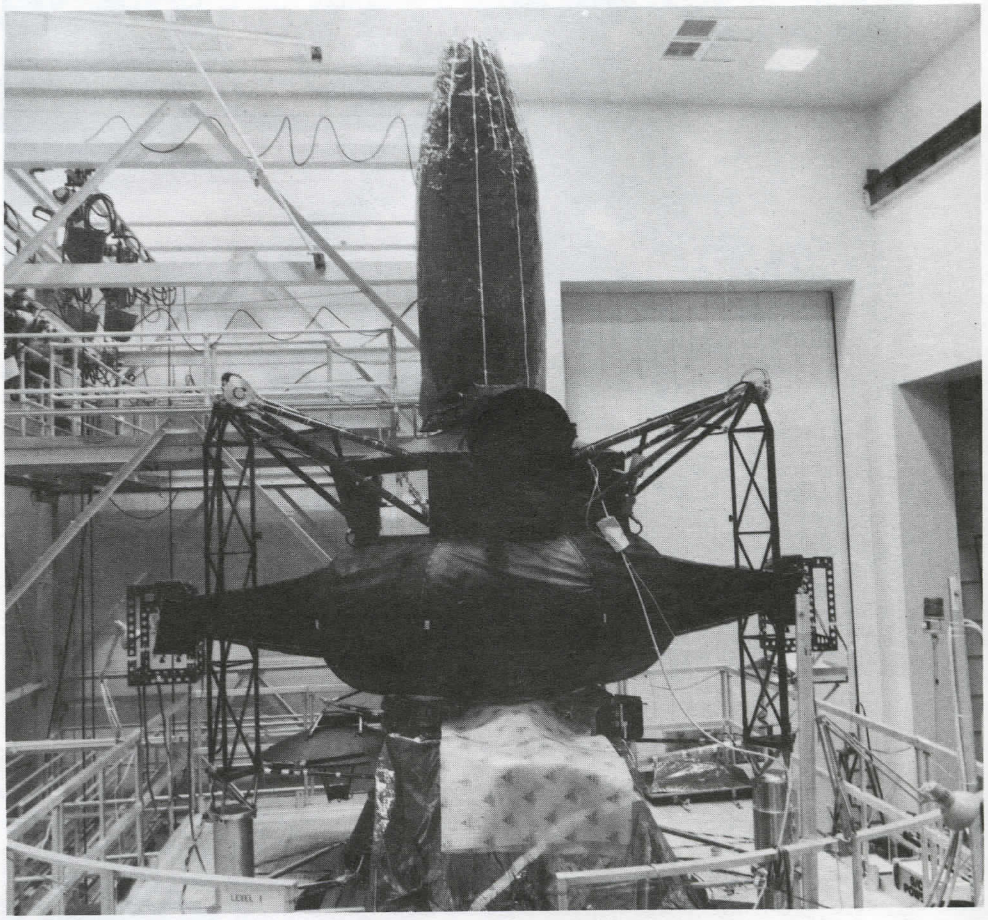

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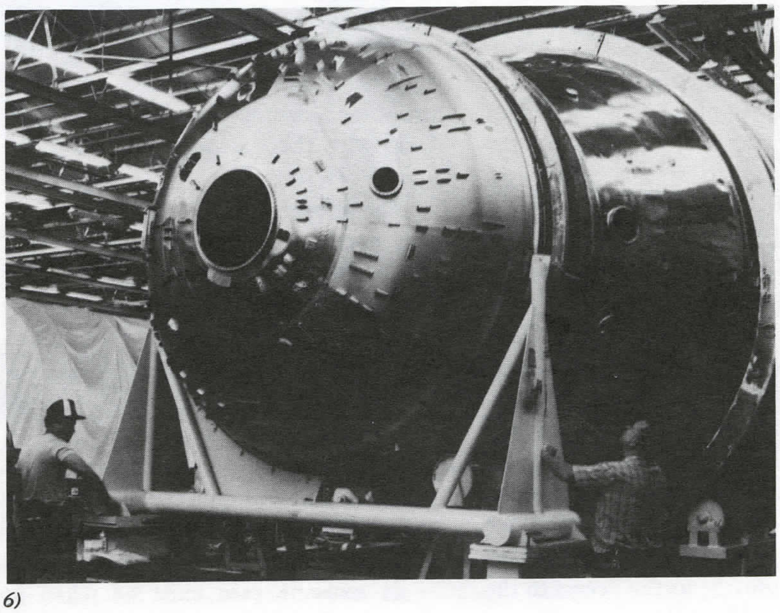

General Dynamics Convair

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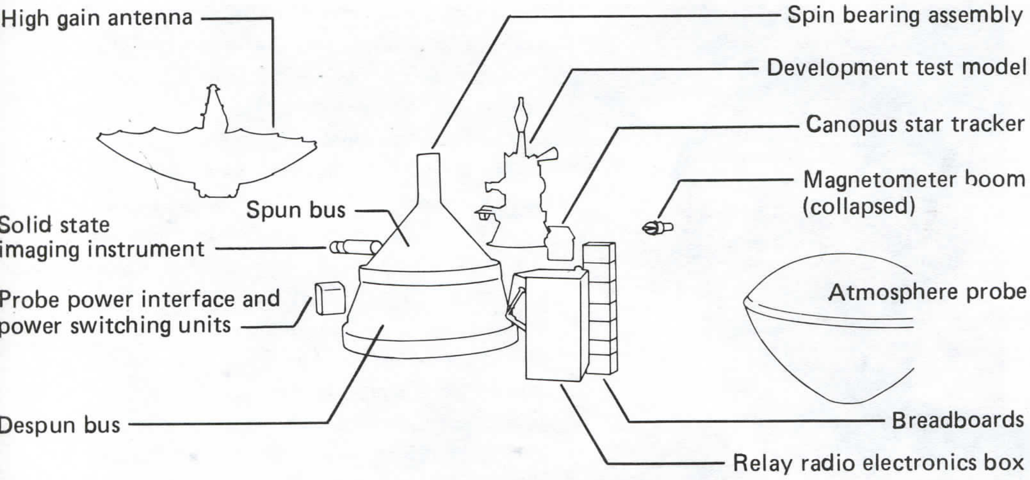


1) German engineers Siegfried Kremmer (left) and Henning von Bassewitz pose with the 400-newton main engine of the Orbiter's retropropulsion module (RPM) delivered to JPL in May by Messerschmitt-Bölkow-Blohm, GmbH.

2) Test personnel check out the RPM during electrical integration with the spacecraft. "Erector-set" cages protect the thruster modules at the ends of cantilevered booms.

3) The major elements of the spacecraft were stacked in launch configuration for the first time in mid-July. Here, the Probe is guided into place. The RPM's thruster booms are in the background.

4) The RPM is lowered over the spin bearing assembly as stacking continues.

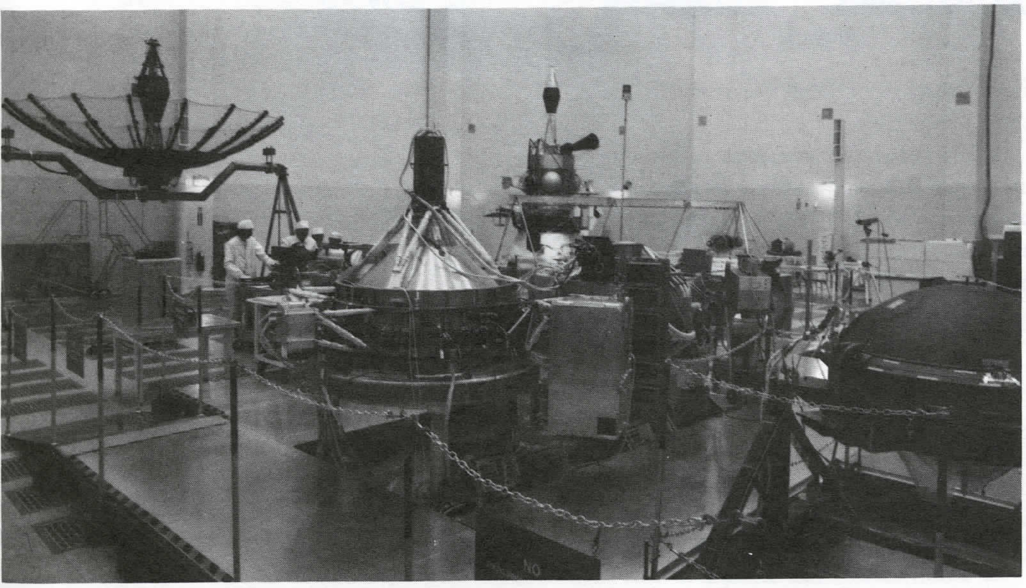
5) In August, the spacecraft moved to JPL's Environmental Laboratory for vibration testing in launch configuration. The high gain antenna is encased in protective sheeting for the test. Thermal blankets have been added to the RPM's tanks and booms.

6) Full scale structural model of the Centaur upper stage undergoes test at General Dynamics Convair.

7) Prior to stacking, the major elements of the spacecraft were stationed on the floor of the SAF clean room.

8) Writer Arthur C. Clarke (left) and Dr. Mueller share a chuckle with John Casani during a visit to the clean room in May.

9) In early August, developmental hardware went to JPL's 10-foot space simulator for a Superzip test — the pyrotechnic separation of the despun section from the upper spacecraft adapter — in a hard vacuum and a cold environment (−38°C).



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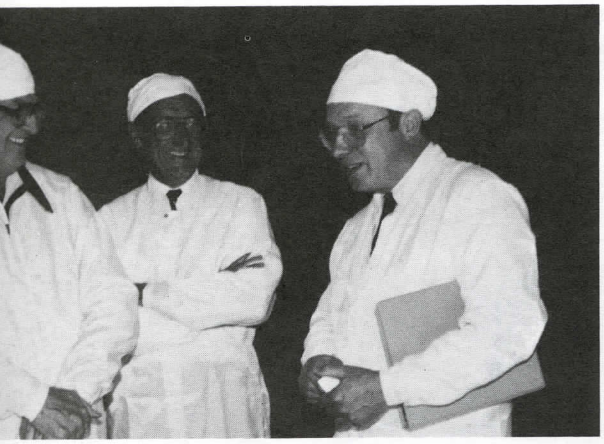
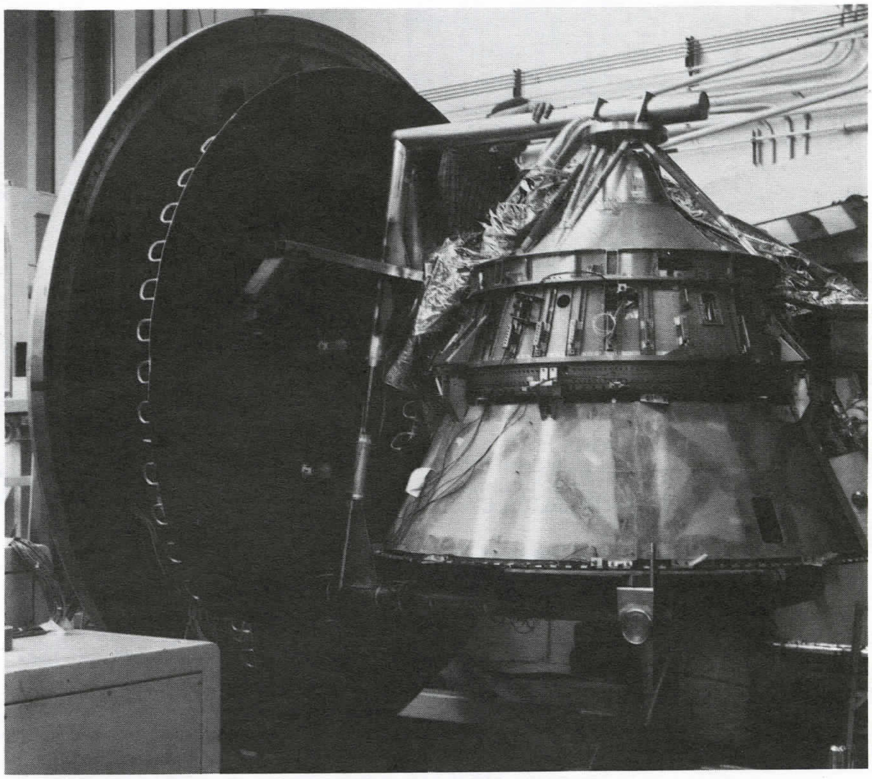


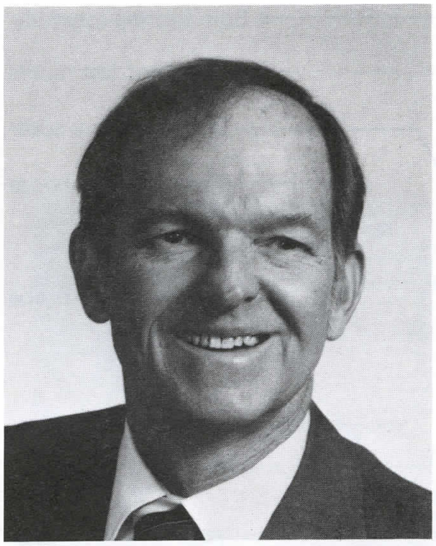


9)

Meet the Team

Al Wolfe has been Galileo's Deputy Project Manager since the project's inception in 1977, and describes himself "as a jack of all trades, in a sense." His primary duties include supporting Project Manager John Casani and acting as Project Manager when John is away on business. He also is in charge of project change control for both hardware and software, controlling the interfaces between major elements of the Project.

A Caltech graduate, Al first worked on optical instrumentation at Aberdeen Proving Grounds in Maryland. While installing tracking telescopes at White Sands, New Mexico, he met former JPL director William Pickering, and in 1952 Al came to JPL to work on development of test instrumentation. He was involved in the LOKI program, the Reentry Test Vehicle (RTV) program (the forerunner to Explorer I), and in Explorer itself. He was Spacecraft Manager for Ranger programs, Mariner V, and the Viking Orbiter.

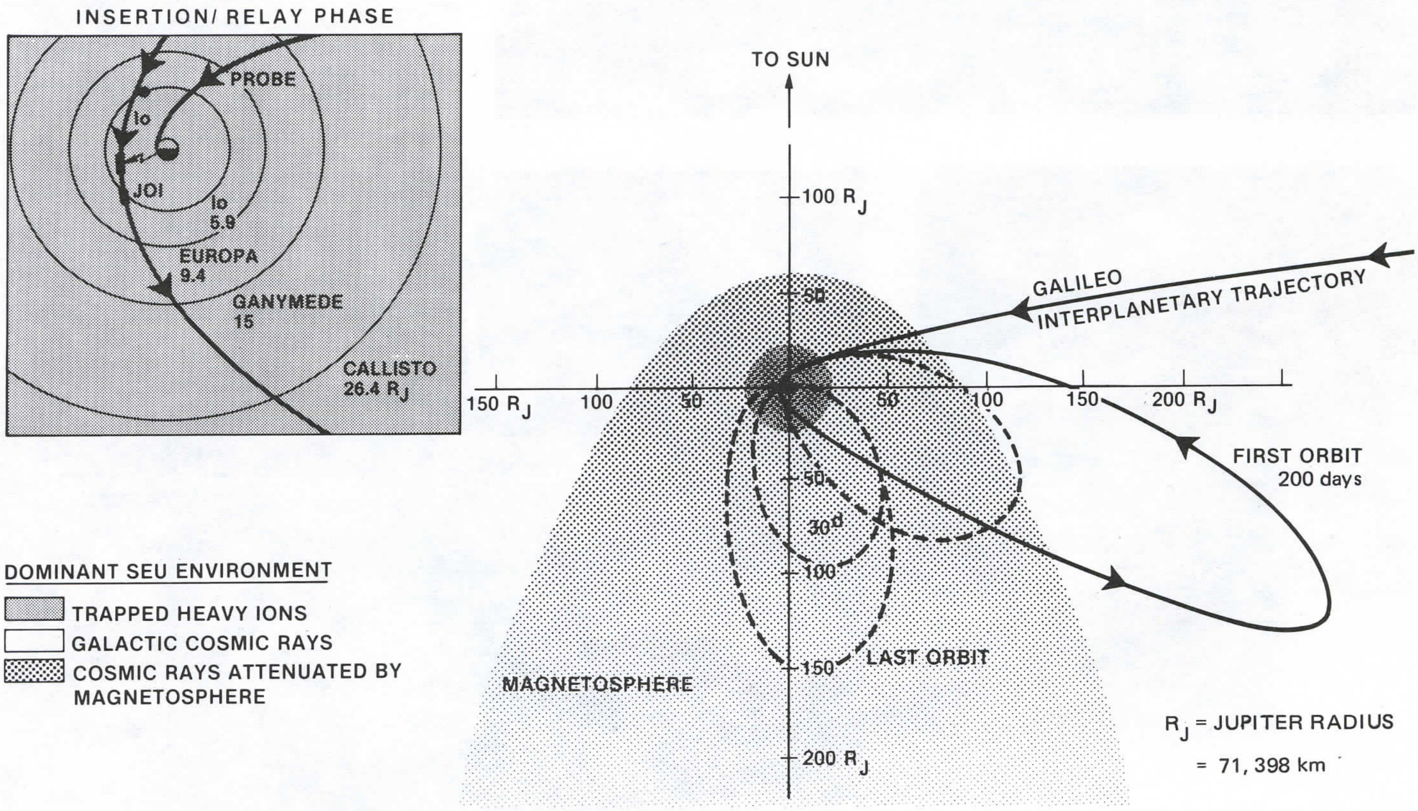


Al Wolfe

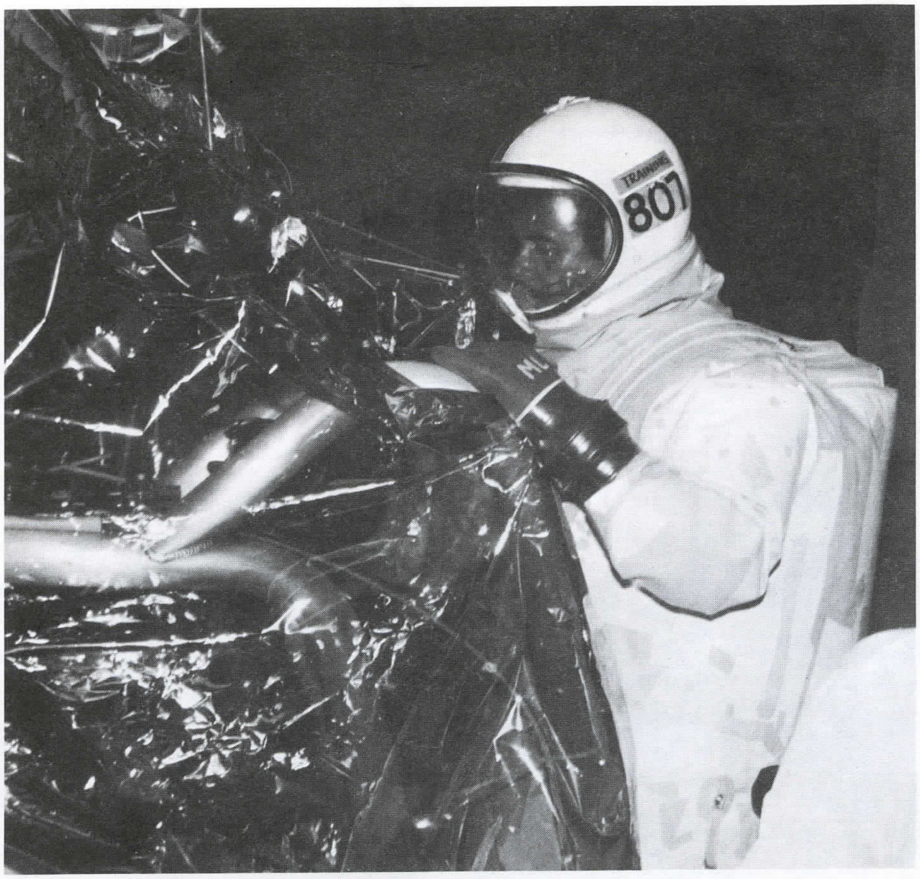
While spacecraft continue to become more sophisticated, adding to the complexity of the job, the basic problems and solutions are not too different from project to project, Al notes. "There are always the problems of parts, processes, and workmanship, and the solutions lie in the quality and dedication of the Project team," he says.

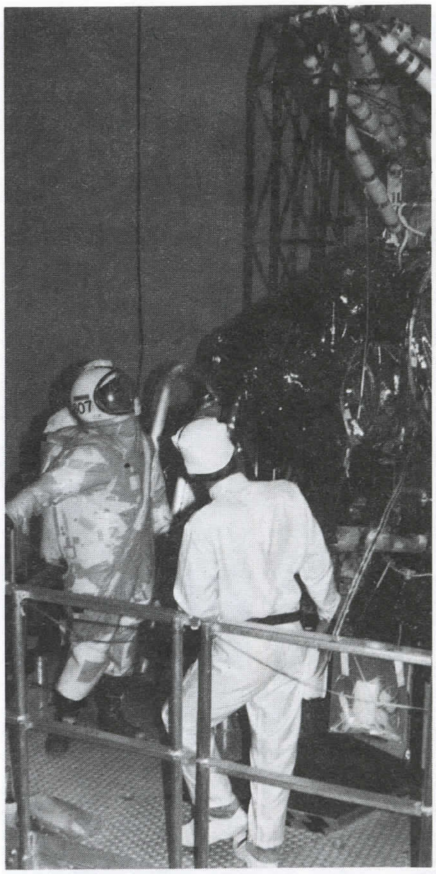
Galileo in particular is a highly sophisticated design, with its microcomputers, larger memories, dual-spin configuration, and entry probe. It pushes the technology in the solutions of the dual-spin and probe entry requirements, in instrument development, and in the development of components to withstand the cosmic ray and jovian radiation environments. The sophisticated design, coupled with the interactions among the NASA Centers and European organizations, makes the project a real challenge. Says Al with a smile, "I'm anxious to see how that monster works in space!"

Al and his wife Georgie live in nearby Flintridge and enjoy visiting their grown daughters in San Diego and Denver, where there are also two grandchildren. Al lists his hobbies as travel and photography.



Due to concern that heavy radiation dosages near Jupiter could cause bit flips in Galileo's computers, radiation-hardened chips have been designed. The orbiter's closest approach to Io (at 4 to 5.2 R_J) will be in the most dangerous area of the single event upset (SEU) environment, but the spacecraft will be exposed to galactic cosmic rays through its lifetime.





Photos by Jim Lumsden

Hank Delgado assesses access to the RPM on the stacked spacecraft while he wears a protective suit. The suits will be worn when the hypergolic propellants are loaded into the spacecraft prior to launch from Kennedy Space Center in May 1986.

RPM Access Test

Men in SCAPE units stalked the Galileo spacecraft in August, but their mission was merely a rehearsal for the real thing in 1986.

The men, part of the team supporting Galileo's propulsion subsystem, donned Self-Contained Atmospheric Protective Ensembles — bulky pressurized suits — to test access to the retropropulsion module (RPM) while it is mated to the rest of the spacecraft.

"Always before we've had the opportunity to approach our subsystem and work on it before it was mated with the other subsystems," explains Hank Delgado, Propulsion Group Leader. "Galileo will be shipped to the Cape already mated, so this was a test to see how well we will be able to perform our propellant loading operations at the Cape. We found that the scaffolding needs to be modified to provide us full access to the RPM while we're suited up."

The Galileo program has adopted an operational concept known as "ship and shoot"; that is, all system-level test and integration activities will be completed at JPL prior to shipment and the spacecraft will be shipped to Cape Canaveral in flight-ready configuration. On prior missions, spacecraft have been disassembled for shipment and reassembled at the Cape for final integration and testing. Galileo operations at Kennedy Space Center will be limited to final spacecraft launch readiness activities, propellant loading, verification of interfaces with the shuttle, and countdown and launch tests.

The propellants will be loaded into the spacecraft at one of KSC's Payload Processing Facilities prior to mating with the Centaur stage. Galileo's propellants, monomethyl hydrazine and nitrogen tetroxide, are stored in four separate tanks, two tanks for each propellant. It will take about a day per tank to prepare for loading and to load the propellants. These liquid propellants are toxic and hypergolic — they ignite spontaneously upon contact with each other — so extreme care must be taken in their handling. In addition, their vapors are corrosive, so the sensitive science instruments and spacecraft surfaces must be protected as well. The spacecraft will be draped with protective sheeting as a safety precaution.

Personnel handling the propellants will wear the 55-lb suits equipped with backpacks of liquid air (a mixture of 29% liquid oxygen and 71% liquid nitrogen). which is vaporized to provide conditioned air for breathing, ventilation, temperature control, dehumidifying, and suit pressurization. The suits are completely sealed and have communications equipment as well as pressure relief valves to provide ease of motion.

"These suits are really sophisticated," says Hank. "I could perform brain surgery in one if I had to!"

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The Galileo Messenger

Issue 12 December 1984

From the Project Manager

NASA Administrator James Beggs has agreed to add an asteroid option to the Galileo mission and to change the Jupiter arrival date from August 29, 1988 to December 10, 1988. The option will permit a later decision to fly by the asteroid 29 Amphitrite in December 1986.

The approval follows two years of study by numerous scientific groups, mission designers, and program officials to devise a means to include this option. If the option is elected – a decision to be made after launch – it would add a significant scientific "first" to the Galileo mission.

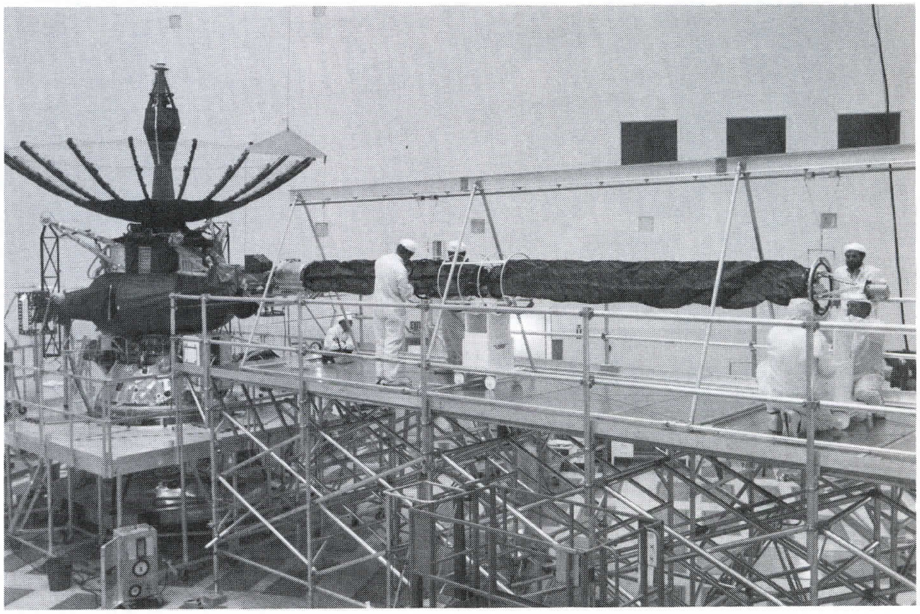
The National Academy of Sciences, as well as the Solar System Exploration Committee (SSEC), has identified the investigation of the asteroids by spacecraft as an essential element of a balanced planetary exploration program.

The flyby has the unanimous endorsement of the Galileo Project Science Group and the Small Bodies Working Group of the SSEC.

The asteroid flyby will be treated as an add-on, not a primary mission objective, and will not be permitted to compromise the basic mission objectives or to add any risk to the Jupiter mission.

A decision on whether or not to exercise the flyby option will be made about two months after launch, based on an assessment at that time of the health of the spacecraft, particularly the attitude control system and the mission operations system.

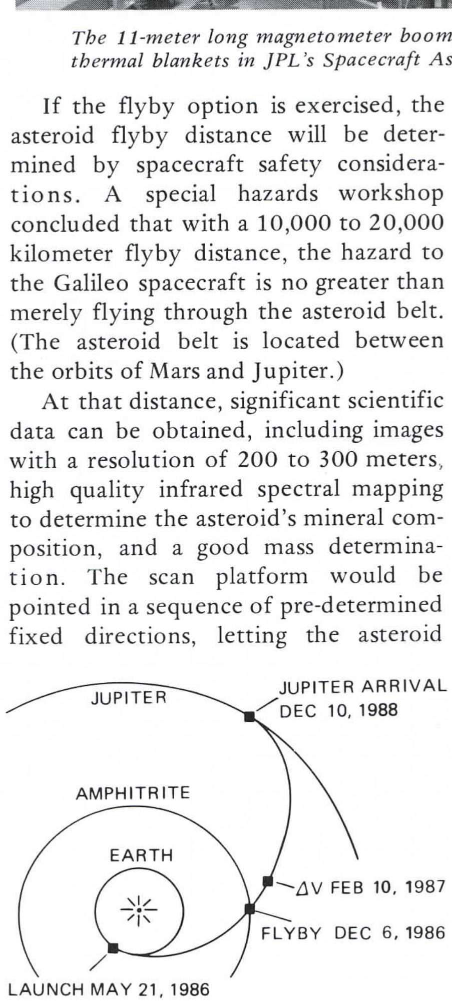
A new trajectory containing both Amphitrite and Jupiter, constrained by the launch vehicle energy and existing launch window, has been developed. The trajectory will result in a delay in the Jupiter arrival date from August 1988 to December 1988. No mission operations work or added software capability related to the flyby will be accomplished prior to launch other than that required to plan the primary mission based on the asteroid flyby trajectory.



The 11-meter long magnetometer boom, suspended in a special truss, is fitted with thermal blankets in JPL's Spacecraft Assembly Facility.

If the flyby option is exercised, the asteroid flyby distance will be determined by spacecraft safety considerations. A special hazards workshop concluded that with a 10,000 to 20,000 kilometer flyby distance, the hazard to the Galileo spacecraft is no greater than merely flying through the asteroid belt. (The asteroid belt is located between the orbits of Mars and Jupiter.)

At that distance, significant scientific data can be obtained, including images with a resolution of 200 to 300 meters, high quality infrared spectral mapping to determine the asteroid's mineral composition, and a good mass determination. The scan platform would be pointed in a sequence of pre-determined fixed directions, letting the asteroid drift through the instruments' field of view before moving to the next position.

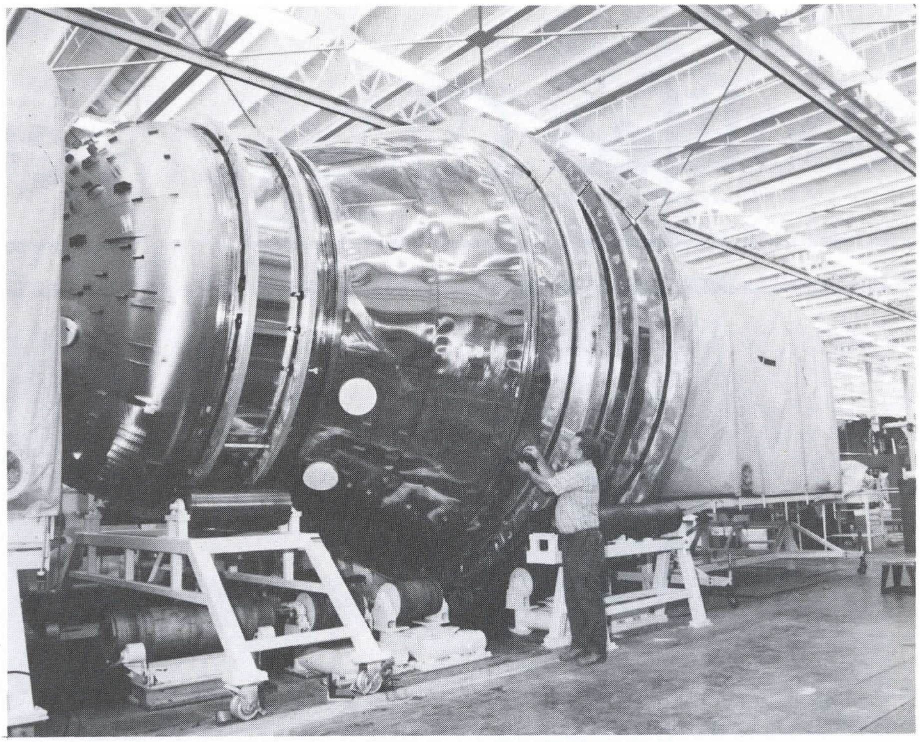


Amphitrite is a large, main belt asteroid about 200 kilometers in diameter; from Earth it appears as the twelfth brightest asteroid. As such, it is an outstanding candidate for exploration. Amphitrite lies in a part of the asteroid belt subject to gravitational perturbations by Jupiter and might be a source of some of the meteorites that impact Earth.

The effect on the Jupiter mission will be minor. Since the flyby requires added expenditure of propellant in the early mission phase, the number of tour orbits of Jupiter would be decreased from 11 to 10. Consequently, the length of the tour has been extended from 20 months to 22 months to permit the achievement of all the major objectives previously encompassed by the 11-orbit tour.

There will be no near-term cost impact due to the incorporation of the flyby option. Major added costs, estimated at $20-25 million, are attributable to a five-month mission extension due to the delayed arrival date and increased tour time. □

– J. R. Casani



General Dynamics Convair

Centaur's thin-walled stainless steel tanks will hold about 21,000 kilograms of liquid oxygen and liquid hydrogen propellants in a 5:1 ratio.

Centaur G′

The Space Shuttle will lift the Galileo spacecraft to Earth orbit, but it will take a powerful upper stage rocket to boost the 2-1/2 ton spacecraft out of Earth orbit and on toward Jupiter.

The expendable high energy upper stage for Galileo is the Centaur G-Prime (G′), a new version of the Centaur stage that has launched all of the United States' planetary missions since 1962. The combination of Centaur with the Titan booster launched the Helios, Viking, and Voyager spacecraft. The Atlas/Centaur combination boosted a series of Surveyors (7) to soft landings on the moon starting in 1966, and Atlas/Centaurs continue to launch Earth orbiting communications satellites and various Earth-orbiting and planetary scientific satellites.

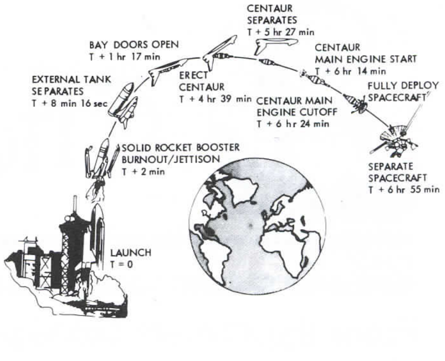
Galileo's Centaur is being built in San Diego, California at General Dynamics Convair Division, under contract to NASA/Lewis Research Center, Cleveland, Ohio.

Development of the Centaur stage for use with the Shuttle began in July 1981. Colloquially known as the "wide-body" Centaur, the original rocket configuration has been widened to provide increased propellant capacity while accommodating longer payload length. The first use of the wide-body will be in May 1986, when Ulysses (formerly the International Solar Polar Mission) will be boosted toward Jupiter on the initial phase of its journey over the poles of the Sun. The Galileo launch will follow about ten days later.

The Shuttle will carry the mated Centaur/Galileo combination to low Earth orbit, about 130 nautical miles. About six hours after liftoff, on about the fourth orbit, the Galileo/Centaur combination will be prepared for release from the Shuttle bay. The Centaur integrated support structure (CISS) will erect the rocket to about 45 degrees and then springs will gently push it away from the Shuttle at about one foot per second. The Centaur burn will begin about 45 minutes after separation from the Shuttle.

Centaur's thin stainless steel tanks will hold about 21,000 kilograms of propellants, in a 5:1 ratio of oxygen to hydrogen. This is an increase of about 50 percent in propellant load from the Atlas/Centaur. Two Pratt and Whitney engines will develop about 16,500 pounds of thrust each. At the end of the 9-1/2 minute Centaur burn, Galileo will be travelling over 50,000 mph.

After Centaur main engine cutoff, Galileo will unfurl its antenna, deploy its instrumented booms, and fire pyrotechnic devices to sever the joint holding it to the Centaur. After separation, the Centaur will maneuver away to avoid a collision with and/or contamination of the spacecraft. Centaur's guidance and control electronics are provided by Honeywell and Teledyne Systems Corporation.



The major weld of the tank structure of the Centaur G′ designated for Galileo was completed in October 1984, and the innards—propellant loading probes, vent pipes, etc.—are now being installed. Completion of final assembly is scheduled for March 1985. After a three-month checkout, the Centaur will be shipped via airplane to Cape Canaveral in July 1985. Tanking tests will be conducted in October 1985 at Complex 36, and in February 1986 a "wet" (propellants loaded) Centaur countdown demonstration test will be performed using the Shuttle, Centaur, and the development test model of the Galileo spacecraft.

Joan Sherley, liaison between Convair and JPL for Galileo, notes that interface activity for the Galileo mission is more complex than for previous planetary missions, since use of the high energy upper stage in the Shuttle is brand new.

Both Galileo and Ulysses carry radioisotopic thermoelectric generators (RTGs) to provide internal electrical power. Prior to launch, the RTGs must be cooled, and one challenge has been designing the system to run cool water lines from the Shuttle, along the CISS and Centaur stage, to the field joint on Galileo's spacecraft adapter, and then to run the hot water lines back down.

Plumbing lines for gaseous nitrogen must also run to the Galileo orbiter's science instruments to avoid contamination prior to separation from the Shuttle. General Dynamics is integrating the JPL-provided airborne purification equipment box into the CISS and running the plumbing lines.

"The launch opportunity (a ten-day period in May 1986) gives a big lever arm," says Marty Winkler, Director of the Shuttle/Centaur Program at Convair. "It can't be late, and it has to be built right. Motivation in the plant here is very high for those reasons. When you think through the complexity of everything that has to go right, it's monumental!" □

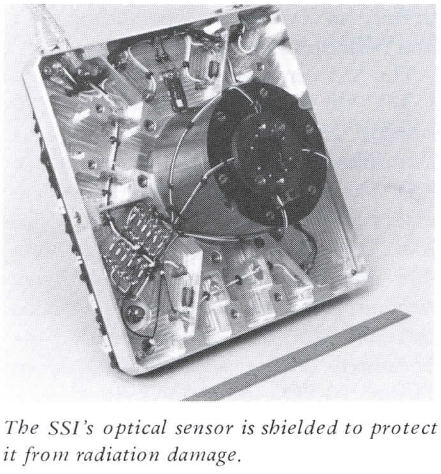
Solid State Imaging

Building on the experience of the Pioneer and Voyager programs, Galileo will obtain about 40,000 images containing useful scientific information about the jovian system — the planet Jupiter, its atmosphere, rings, satellites, and magnetosphere.

The Galileo orbiter will carry a 1500-mm narrow angle telescope inherited from Voyager. Along with an image sensor and electronics, this forms the solid state imaging subsystem (SSI).

"Galileo's 22-month tour of the jovian system will allow long-term studies of Io's active volcanoes and Jupiter's atmosphere. The satellites will be mapped at a wide range of angles and lighting conditions and at very high resolution, utilizing satellite flybys that are as much as 20 to 100 times closer than ever achieved before," notes imaging team leader Michael Belton of the National Optical Astronomy Observatories.

"The design of the SSI was dictated by a combination of goals and constraints," explains SSI science coordinator Ken Klaasen. "The need to study both atmospheric motion and geologic formations dictates a high-resolution large-format camera, while the need to study the composition of satellite surfaces and the vertical structure of features in Jupiter's atmosphere dictates the use of several spectral filters within the range 400 to 1100 nanometers. Accurate mapping and atmospheric velocity measurements require a camera with excellent geometric fidelity, while precise photometric requirements necessitate a linear detector, stable calibration, and adequate data encoding. Low lighting situations, such as observations of the auroras, lightning, and ring system, require a detector of very high sensitivity and an optical system with low scattered light. Constraints on the design included limitations on the available telemetry rate, potential image smearing caused by residual motions in the scan platform, use of large amounts of shielding to protect the instrument from Jupiter's harsh radiation environment, limited electrical power and mass, and protection from contamination during launch and from propellant byproducts in flight."



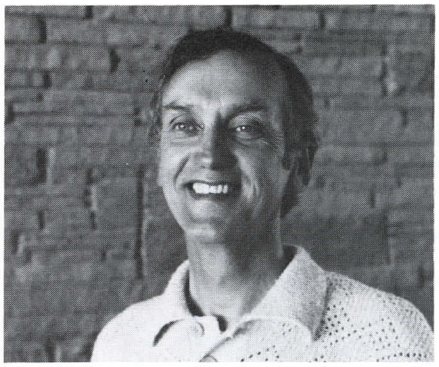
The SSI's optical sensor is shielded to protect it from radiation damage.

For the Galilean satellites Io, Europa, Ganymede, and Callisto, the imaging investigators hope to determine the form and structure of at least 50 percent of the satellite surfaces at a scale of 1 kilometer or better. In many images, features as small as 100 meters will be distinguishable. In the very best pictures, the smallest distinguishable features will be 20 meters. Volcanic Io is of prime interest, and in addition to geological studies, the imaging team will try to detect Io's atmosphere and map the source of sodium emissions that connect it with Io's torus.

Since the SSI's wavelength range extends from the visible into the near-infrared, the experimenters will be able to map variations in the satellites' color and albedo (reflectivity) that show differences in the composition of surface materials.

Imaging data will also pinpoint the location of each satellite's spin axis, their rotation rates, and their shapes and dimensions with high precision.

As opportunities arise, the camera will also turn toward Jupiter's smaller and more distant satellites to obtain information on the form and structure of their surfaces, colors, and albedoes. This information will aid in determining the origin of these small satellites which were captured by Jupiter sometime after its formation. New small satellites may be found in or near Jupiter's rings.

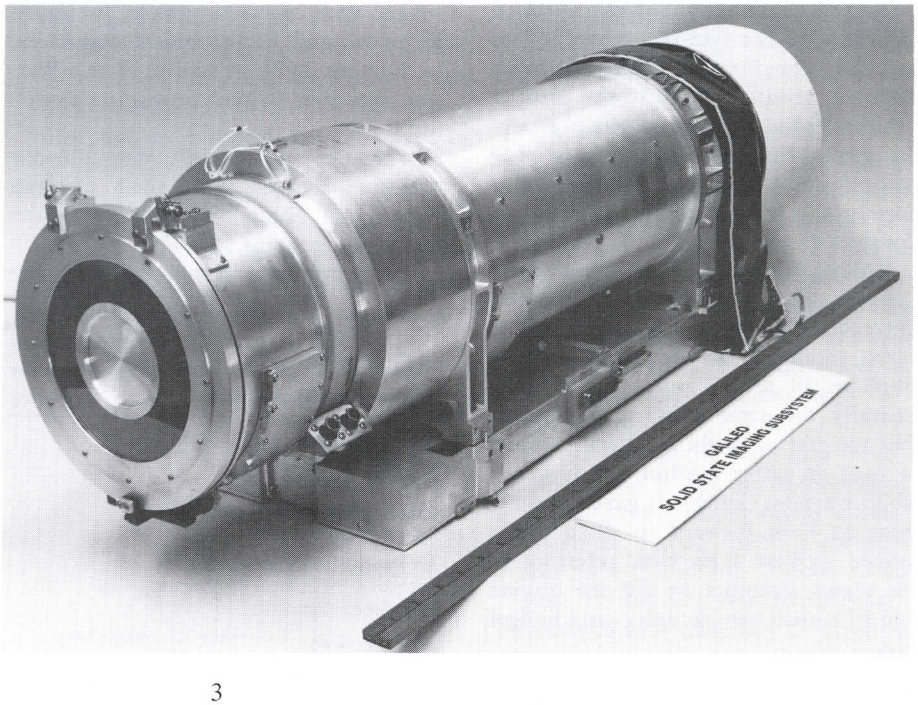


Michael Belton

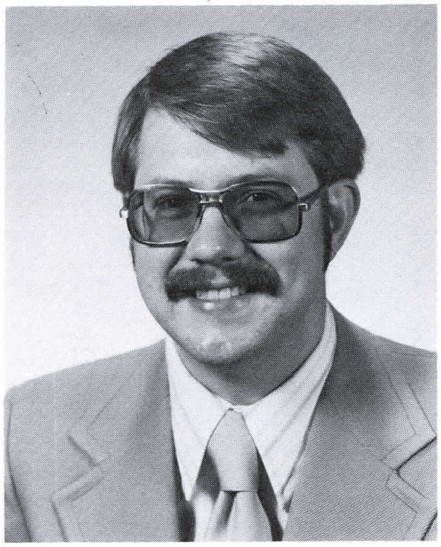
Images of features such as the Great Red Spot, "barges", and white ovals will yield new information on their physical structure and will aid in distinguishing between mass motion and wave motion. Relative motion among clouds at various altitudes will be tracked to learn how local wind flows maintain themselves. A detailed, long-term study of Jupiter's largest atmospheric motions will show how the planet transports energy from the equator to the poles and maintains its equilibrium. The SSI's near-infrared filters will allow us to "see" at different levels in the atmosphere to study relationships among vertical structure, color, and morphology.

The imaging instrument is mounted with three other optical instruments on a movable platform bolted to the nonspinning portion of the Galileo orbiter. This scan platform can be slewed up, down or sideways to point the instruments. The optical axes of the instruments — the SSI, the near infrared map-

see page 4



Meet the Team



Torrence Johnson

A sign above the door of Torrence Johnson's office reads: "Self-Guided Tour Interest Point 36A: Typical Scientist's Office". A peek inside reveals a landslide of papers, wallboards charting Congressional processes and the resolution of Galileo's images of the jovian satellites, a tiny figure of Yoda sitting atop a desktop computer, and a sign from *Star Wars*: "The Force is With Us."

As Galileo's Project Scientist, Torrence is the principal science advisor to the project, the principal science interface between the project and the principal investigators on Galileo's science experiments, an ex-officio member of all of Galileo's science teams and working groups, and chair of the Project Science Group.

Torrence's involvement with Galileo goes back to the mid-70's when he was part of the Mariner Jupiter Uranus planning group and then the Jupiter Orbiter Probe science working group, the group that developed the science rationale for Galileo and "sold" the mission to the science community and to Congress.

"All of this planning was done before Voyager was even launched," noted Torrence. "When the Voyager results began coming in, we had to change the emphasis in a few areas, but it's still basically the same mission in concept that we started with. It's been exciting to have an active mission – Voyager – while we plan Galileo. It gave us something to look forward to when things looked darkest," he said, referring to the many attempts to kill the project due to launch vehicle delays and budget cuts.

"Galileo was viewed as the baseline for the planetary program. If we had lost Galileo we would have lost the whole planetary program. Networking efforts at high levels by the scientific and industrial communities saved Galileo, and also opened the door for new missions such as the Mars Observer," he reflected.

"The scientists involved have a big stake in Galileo – at least 12 years of thinking and planning, and 5 to 10 years of hard work building instruments and writing software. As scientists, we are very lucky to have the opportunity to be involved in the operational phase of the mission and I get a lot of personal fulfillment from that as the results come in," he concluded.

Torrence earned his undergraduate degree in physics from Washington University, St. Louis, Missouri, graduating with honors, before doing his doctoral work at Caltech on the albedo and spectral reflectivity of Jupiter's Galilean satellites. He was a research associate at MIT for several years before returning to Pasadena and JPL. He is currently a member of the Voyager imaging science team, a co-investigator for Galileo's near infrared mapping spectrometer, a guest investigator for the Hale Observatories, and recently spent two years as a visiting associate professor of planetary sciences at Caltech.

Torrence is a fellow of the Explorers Club and the American Association for the Advancement of Science, a founding member of The Planetary Society, and a member of numerous other professional organizations.

As his job has thrust him into the public eye, Torrence has become a sought-after public speaker for both technical and non-technical audiences. In January 1985 he will present a Watson lecture at Caltech on Jupiter's satellite Io.

Torrence and his wife Mary Eleanor live in Altadena with their children Aaron and Eleanor, and enjoy scuba diving and cooking. □

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from page 3

Imaging...

ping spectrometer, the ultraviolet spectrometer, and the photopolarimeter-radiometer – are aligned so they are looking at the same areas, and their data will be correlated. For example, the use of Voyager's imaging and infrared data confirmed the possibility and extent of lava lakes on Io.

"The SSI uses a Cassegrain telescope with a 176.5-mm aperture, and a fixed relative aperture of f/8.5," explains instrument manager Maurice Clary. "It is focussed on infinity. Light from a scene is collected on an 800 line by 800 column solid state silicon image sensor array called a charge-coupled device (CCD). Charge is transferred by rapidly cycling the voltage level applied to the 640,000 gates in this integrated circuit. Analog video data from the CCD are converted to digital bits, sent to the telemetry system, and relayed to Earth. There, the bit stream is relayed from the tracking stations to image reconstruction equipment at JPL."

An eight-position filter wheel is stepped on command to obtain images of scenes through several different filters which may then be combined electronically at Earth to produce color images. There are 28 selectable exposure times between 0.004 and 51.2 seconds. Galileo's spectral range is three times that of Voyager, and its field of view is 8.13 x 8.13 milliradians. The resolution is about 34 line pairs (of the 800 x 800 sensor array) per millimeter.

Since high levels of neutrons emitted by Galileo's onboard power sources could degrade the image quality the camera's CCD is cooled to –110°C to eliminate the problem. The CCD is protected from Jupiter's natural radiation by a 1-cm thick tantalum shield. While transient radiation-induced effects may be seen when the spacecraft is in the heaviest radiation environment near Jupiter, no damage is expected up to a total radiation dose of 100,000 rads.

The SSI was designed and assembled at JPL. It weighs 29.7 kilograms (65 pounds) and draws 15 watts. Texas Instruments provided the virtual phase CCD. The SSI uses RCA 1802 microprocessors and contains 600 integrated circuits. The telescope, shutter, and filters were inherited from Voyager but have been improved to better reject off-axis scattered light. The collimator used for pre-launch testing was inherited from Mariner 10. The electronics chassis was fabricated on a numerically-controlled machine at JPL.

The Galileo Messenger

Issue 13 July 1985

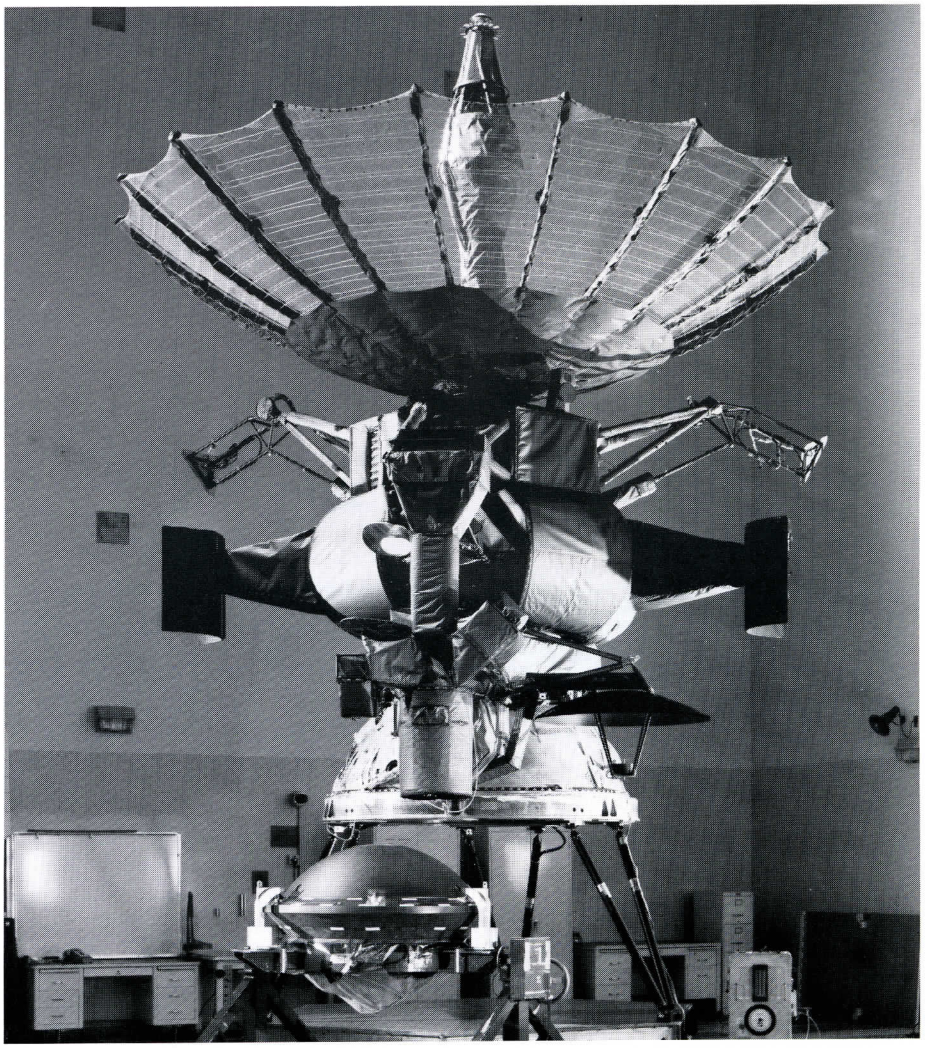
From the Project Manager

In May we passed a major milestone: one year from launch. Galileo is currently scheduled for launch on the afternoon of May 21, 1986, as mission STS-61G, only six days after the launch of Ulysses (a solar polar orbiter). The crew onboard the shuttle Atlantis will be commander David Walker, pilot Ronald Grabe, and mission specialists John Fabian and James von Hoften.

Our time grows short. On January 2, 1986, a mere six months from now, the spacecraft will be shipped to Kennedy Space Center, and there is much to be done before that.

After almost a month of hardware updates and calibrations, the spacecraft is being reassembled at the start of phase 4 of system testing. The spacecraft power will be on 24 hours a day to allow us to increase the number of operating hours on the electronic assemblies. Major tests will be conducted during the first shift, while more limited testing will be accomplished during the second shift. Additional hardware and software updates must also be accommodated in the four months remaining before final preparations for shipping. Major update areas include memory parts, spin bearing assembly rebuild due to slip ring contamination, and flight software.

This issue of the *Messenger* also gives some insight into the scope and complexity of the environmental test program that was completed in March. Although most elements of the spacecraft were tested separately, these environmental tests provided the opportunity to test the spacecraft as a unit in a variety of environments. Tests included vibration, acoustic, pyrotechnic shock, thermal-vacuum, and electromagnetic compatibility.



With the atmospheric entry probe nestled near its base, the Galileo orbiter poses in the assembly room.

Anything that has to perform in space—from astronauts to spacecraft—must undergo rigorous testing. For example, the movie *The Right Stuff* portrays the indignities the astronaut candidates endured at the hands of those determined to test their performance under stressful conditions: whirling them about in centrifuges, shaking them up and down like soda bottles, overstressing their muscle groups to the point of exhaustion, subjecting them to medical tests usually reserved for laboratory animals.

The Galileo spacecraft has fared somewhat better at our hands, but the recently completed battery of environmental tests had the same goal: to test performance under the kinds of stressful conditions to be met during the mission. During the

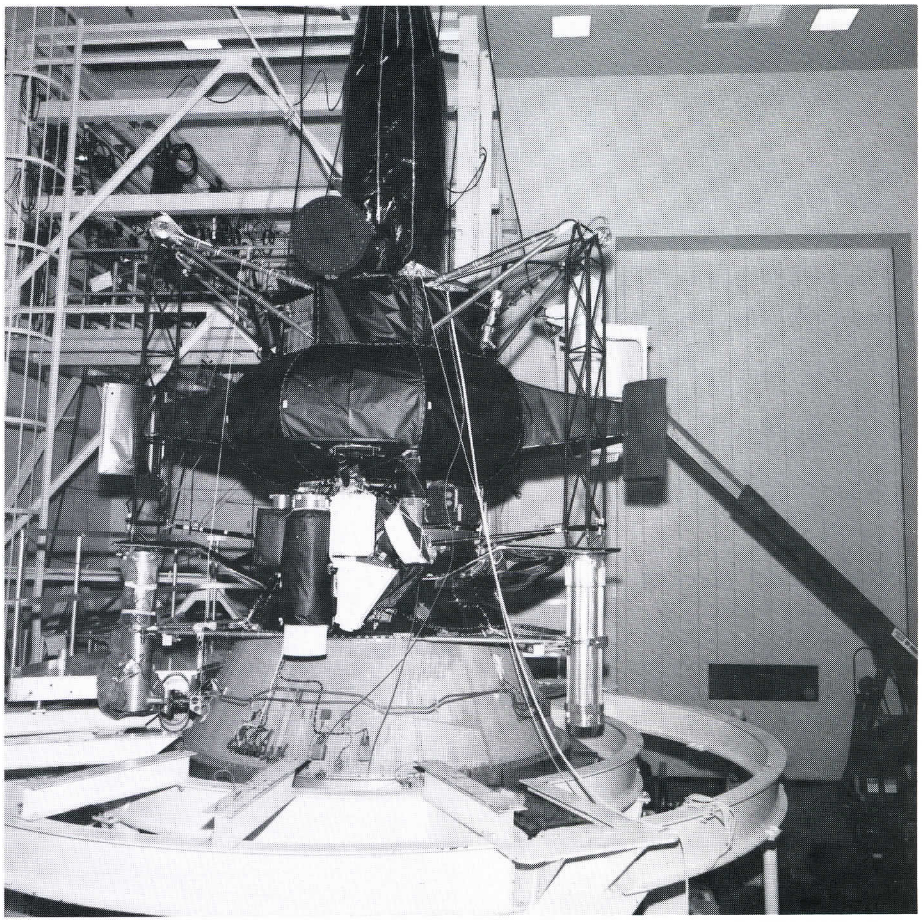
course of the mission, the Galileo spacecraft—both orbiter and probe—will be jostled; shaken; heated; cooled; bombarded with dust particles, cosmic rays, and radiation; and otherwise uncommonly treated. Judged by its performance to date, the spacecraft will handily survive that gauntlet.

The year 1986 promises to be an exciting one for the planetary program, and the successful launch of Galileo will be one of the highlights. ■

– J. R. Casani

Environmental Tests

Vibration, Acoustic, and Pyrotechnic Tests



Surrounded by equipment, the orbiter sits on the shaker table for vibration testing in launch configuration.

Galileo completed its system-level vibration and acoustic testing in September 1984. For the protoflight tests, the spacecraft was in launch configuration—booms and antennas were stowed as they will be during launch. The propellant tanks of the retropropulsion module (RPM) were filled with "referee" fluids to approximate the mass of the actual propellants, and the nonflight high gain antenna and mass mockups of the radioisotope thermoelectric generators (RTGs) were in place.

Vibration

The point of the vibration tests was to verify that the spacecraft will operate properly after being jostled and shaken during liftoff, ascent, and injection onto the interplanetary flight path.

The spacecraft was bolted to the 30,000 force-pound shaker in JPL's Environmental Test Laboratory, and equipped with test instrumentation. Technicians attached 29 accelerometers and strain gages to major elements of the spacecraft to control the vibration, as well as more than 100 additional sensors to take measurements during the test. Approximately 59 of the sensors were also part of an automatic test shutdown system which protected the spacecraft if the vibration exceeded certain limits. For the protoflight test, the spacecraft was vibrated with increasing energy for about 1 minute (a sinusoidal vibration sweep in frequency from 10 to 200 Hertz with a gravitational acceleration of 1-1/2 g's measured at specific points on the spacecraft). Many low level test runs preceded the protoflight test to ensure the safety of the spacecraft itself.

During an all-hands meeting of the Pasadena team members in December 1984, Project Manager John Casani showed a videotape of the vibration test. As the test finished, cheers arose from test personnel, and John wisecracked, "They're cheering because nothing fell off!"

Acoustics

The acoustic tests simulated noise levels in the Shuttle's payload bay during liftoff. The spacecraft was placed in JPL's acoustic chamber, a 10,000-cubic-foot concrete reverberation chamber. Two four-foot square speakers (feed horns) generated the noise levels, and microphones placed around the spacecraft recorded data during testing.

"Preparations for the acoustic test took several days, but the protoflight test itself consisted of just one minute at 142 decibels, to simulate noise levels at launch," said Dave Boatman, dynamics test requirements engineer.

(Note that the noise level of a normal conversation is about 50 decibels, while heavy traffic is about 75 decibels. Each 6-decibel increase represents a doubling of sound pressure.)

Pyrotechnics and Electromagnetics

After launch, a number of small explosive devices will be detonated on the spacecraft to deploy the booms, release the Centaur upper stage, separate the orbiter's spun and despun sections, and jettison instrument covers. Pyrotechnic tests assessed the spacecraft's reactions to the shock of such explosions.

Electromagnetic compatibility tests demonstrated that the spacecraft is compatible with the radio frequency environment generated by outside sources at launch and afterwards, and also that the orbiter and probe do not generate any electromagnetic energy that would be detrimental to the spacecraft, Centaur, or Shuttle.

Solar-Thermal Vacuum Tests

"Stop the movie! Stop the movie!" cries the frantic professor, wildly waving his arms. "Explosions don't go boom in a vacuum!" he protests to a theater full of bewildered tots during a space adventure film.

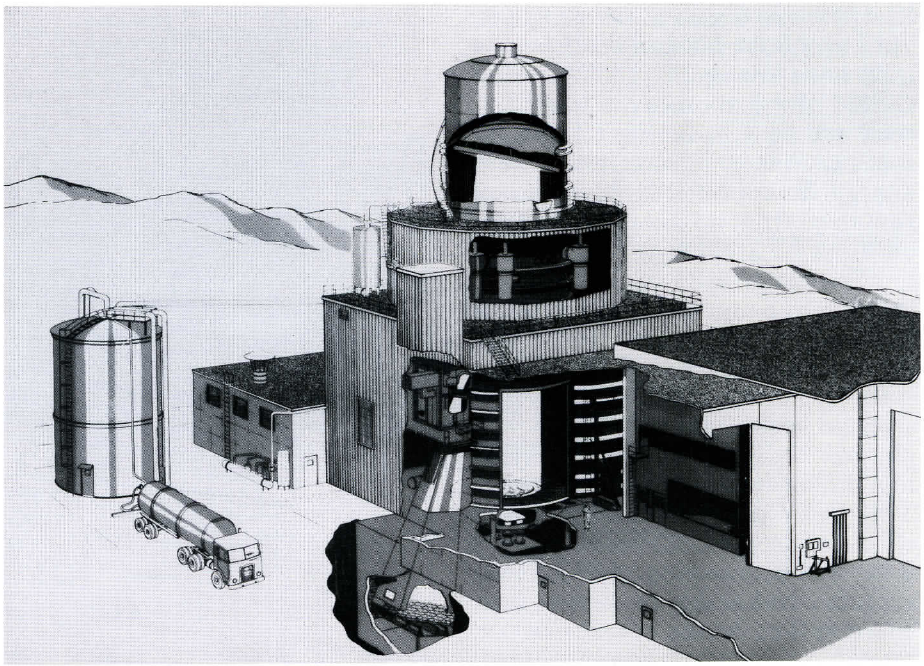
Bud Grace's popular cartoon in a recent issue of *Science 85* points out just one of the unique qualities of a vacuum. There is no sound because there are not enough residual gas molecules to carry the sound. For the same reason, there is no electrical arcing (unlike the lightning we sometimes see during a storm), and there is no heat conductance (unlike the warmth we feel sitting beside a fireplace). There is solar radiation in deep space, however, since electromagnetic radiation (such as light or x-rays) does travel through a vacuum. The trick is to try to produce similar conditions on Earth to test a spacecraft's performance.

JPL's large space simulator has been used to test all of JPL's major flight projects, as well as many other spacecraft. The simulator provides an environment of very low pressure, low temperature, and intense solar radiation.

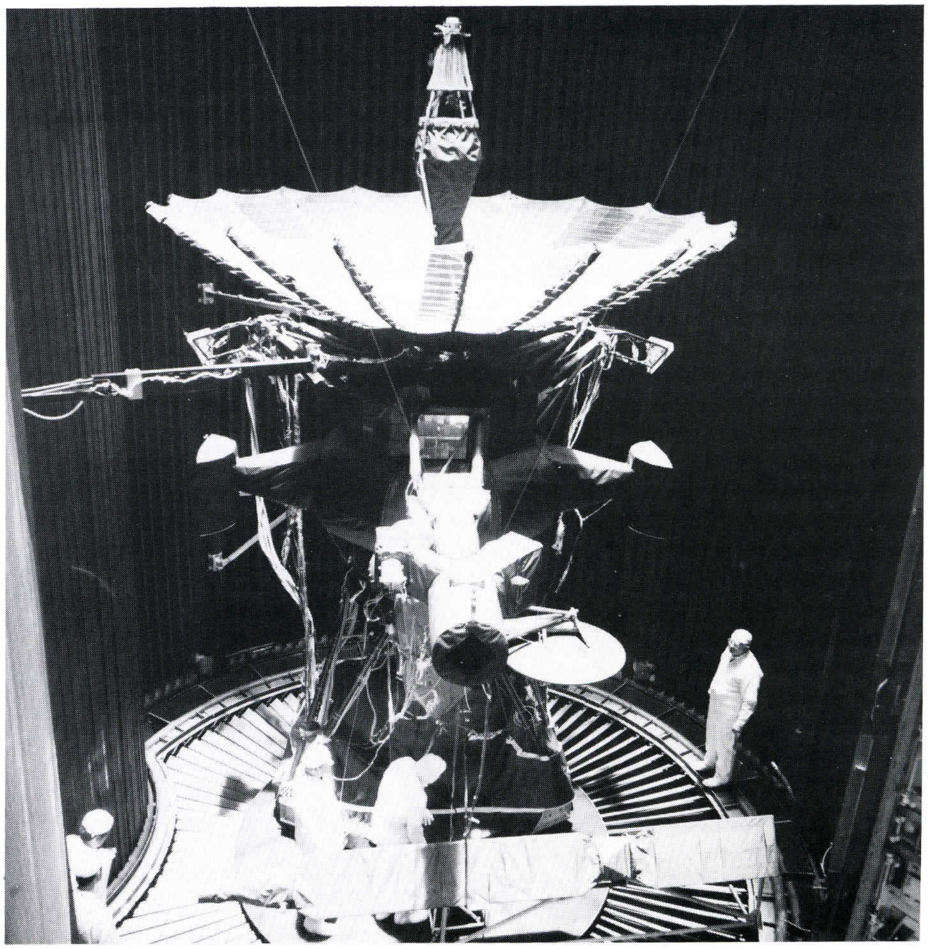
"Because of the unique size and quality of the JPL solar simulation system, this facility is often utilized for testing by non-JPL projects. We have just completed the busiest test period in the history of the space simulator," noted John Harrell, manager of JPL's Environmental Test Laboratory.

The chamber of the space simulator is a stainless steel cylinder 27 feet in diameter and 85 feet high. The 25-foot tall main part of the chamber can be evacuated to simulate the vacuum conditions of space, down to about 5×10^{-6} torr*

A torr is a unit of pressure equal to 1/760 of an atmosphere (the mean pressure at sea level on Earth).



A cutaway of JPL's space simulator shows the 85-foot chamber with the beams from an array of arc lights focussed on a lens at mid-level. The beams are redirected to the main test chamber from the reflecting mirror at the top of the simulator. Liquid nitrogen cools the inner walls and floor of the chamber.



Technicians and engineers make final checks before closing the 25-foot tall door of the vacuum chamber and beginning pumpdown.

(Galileo was tested at about 1×10^{-5} torr, but in deep space the vacuum is as low as 1×10^{-14} torr). Liquid nitrogen cools the inner wall and floor, reaching temperatures as low as −196°C. Solar energy is simulated by focussing radiation from an array of 20- to 30-kilowatt arc lamps.

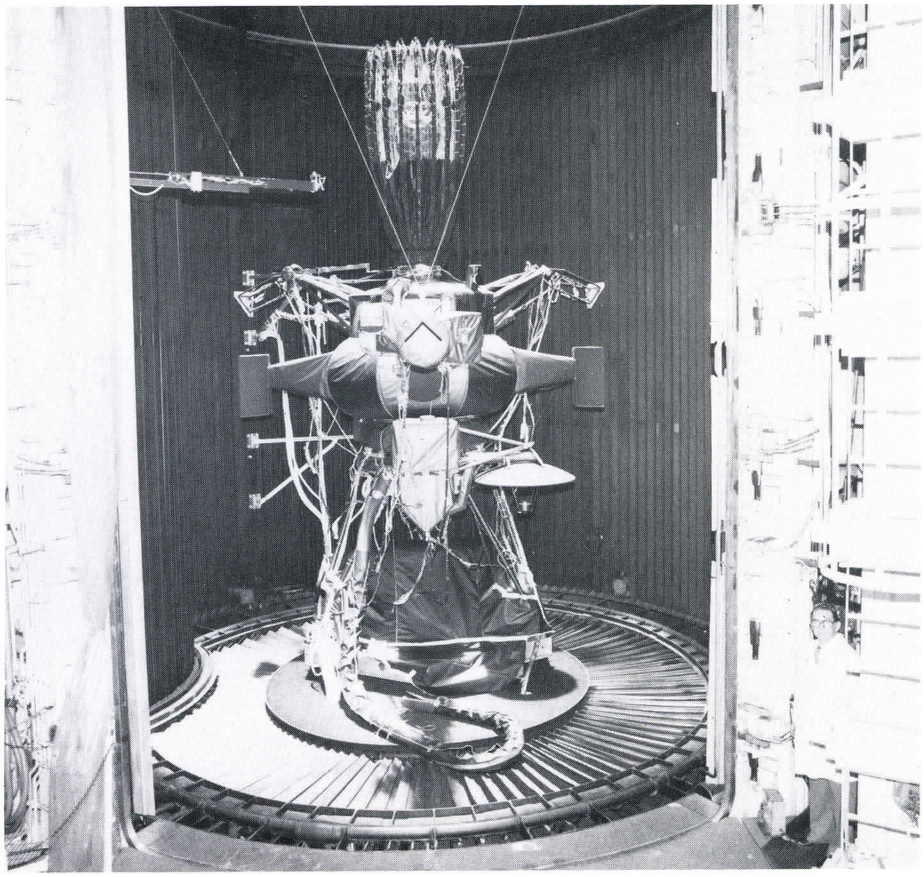
"The top priority of Galileo's thermal vacuum tests was to validate the thermal control model of the Galileo spacecraft by obtaining stabilized temperature data during selected spacecraft modes," explained Wally Castellana, the system environmental test conductor. "The test represents the combined efforts of people from the facilities, spacecraft sequencing, and temperature control areas, as well as the spacecraft real-time operations team."

The spacecraft—orbiter and probe—was first subjected to a rapid pressure reduction similar to that of the Shuttle's ascent from the launch pad. The spacecraft was then operated while being subjected to simulated space environments similar to what might be encountered on the journey from Earth to Jupiter. Similar tests were repeated without the probe to assess the orbiter's performance after probe release.

The tests were conducted in cold and hot modes—from the minimum power state and coldest environment to the maximum power state and hottest environment. One of the coldest environments will be when the spacecraft passes behind Jupiter or a satellite and receives no sunlight, while the hottest environment will be in Earth orbit, when the spacecraft will be nearest the Sun.

The thermal/vacuum tests were run in three phases: the combined orbiter and probe at actual flight temperatures for about 100 hours, the combined orbiter and probe in the hot and cold modes for about 100 hours, and the orbiter alone in the hot and cold modes for about 200 hours. Each test ran around the clock, with several weeks in between each test for updates and modifications.

Data was routed from the spacecraft in the space simulator chamber to the Compatibility Test Area (CTA-21) at JPL (to simulate a Deep Space Network station), to the Mission Telemetry System in the Space Flight Operations Facility (SFOF), to the System Test Complex, and to temperature control data analysis areas at JPL. After analysis at JPL, science data was routed to the home institution of the principal investigator for each experiment.



During thermal-vacuum tests, the antenna was deployed from a "soft" stowed position (above) to fully open.

Thermal Factors

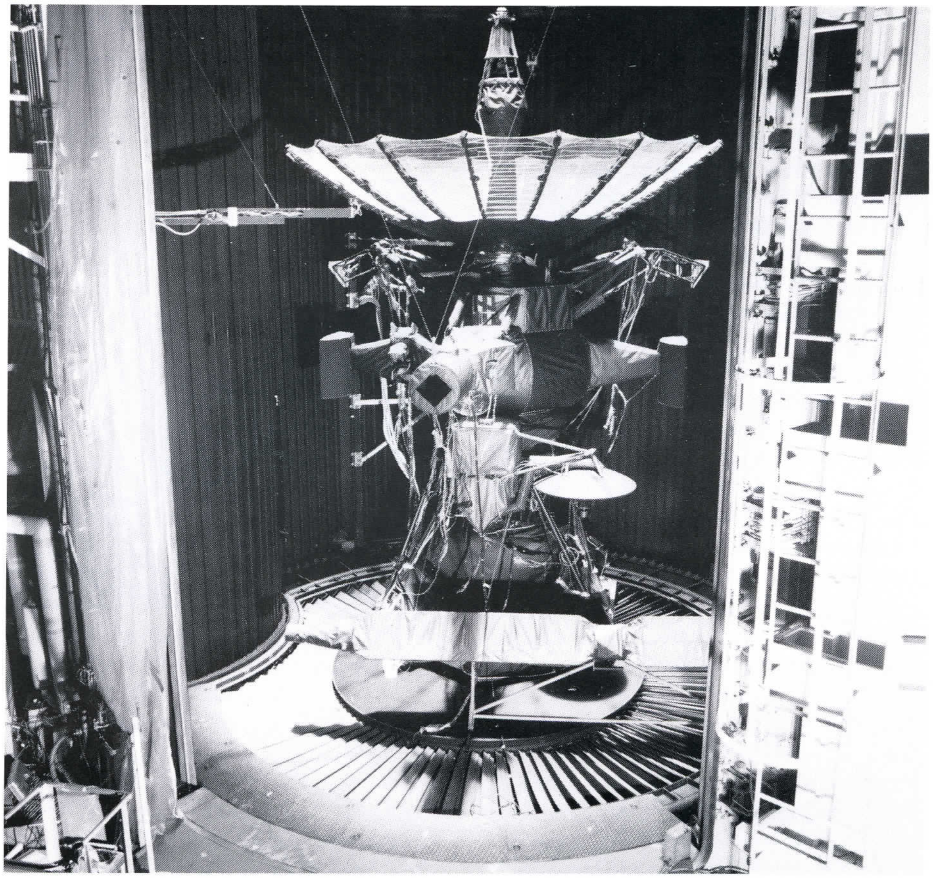
Earlier flight projects verified the thermal design of their spacecraft using a full-scale model of the spacecraft without electronics. Since Galileo's budget did not provide for this step, thermal tests had to be conducted with the flight spacecraft itself.

"Our primary challenge was to design a test that would expose any design problems early, provide the opportunity to understand the thermal behavior of the spacecraft sufficiently so that reliable fixes to those problems could be identified, and permit retesting so that the acceptability of the modified design could be verified. All of this had to be accomplished within the planned 400-hour test duration and with the obvious requirement that the safety of the flight spacecraft not be compromised," said Ray Becker, test director for thermal design and verification.

The thermal design of the spacecraft has to deal with heat from several sources including the Sun (absorbed solar radiation), the radioisotope thermoelectric generators, radioisotope heater units, and the electronics.

Thermal equilibrium onboard the spacecraft is managed by minimizing the variable solar input as much as possible, distributing heat to areas of the spacecraft that need to be warmer, and controlling the rejection of heat to space.

Multilayer thermal blankets cover most of the spacecraft and serve as insulation to retain heat, as a breakup barrier against micrometeoroids, as protection against electrostatic discharge, and to reduce stray light that might interfere with the optical instruments.



The 11-meter long magnetometer boom, in its thermal blanket, was placed at the foot of the orbiter.

Louvers, devices similar to venetian blinds, are driven by bimetallic springs that respond to temperature changes to allow control of heat in the electronics bays on the spun and despun sections and the scan platform. The louvers react to temperature changes resulting from power variations in the electronics.

The spacecraft also is equipped with two kinds of heaters: electrical and radioisotope. The electrical heaters can be turned on or off by command. The radioisotope heaters (RHUs) produce 1 W of power each and are always on. There will be about 70 such heaters on the orbiter and 34 on the probe. Simulated (i.e., electrical) radioisotope heater units (RHUs) were used for the environmental tests.

While most of the spacecraft subsystems tend to operate within the same range—about 5° to 50°C—and were tested from −20° to +75°C, there are many exceptions. The temperature control designers negotiated temperature limits on 85 items that have special temperature requirements, noted Becker. For example, the temperature in the retropropulsion module (RPM) propellant tanks cannot be allowed to rise more than about 5° C because rising temperature causes an increase in pressure in the tanks. (An overpressure could cause a disastrous tank rupture.) In addition, fuel lines must not be allowed to freeze.

Other items with temperature limits include the devices that deploy the Orbiter's booms after the spacecraft leaves the Shuttle. The rate of the boom's movement is controlled by fluid forced through a small hole. The deployment rate depends on the viscosity of the fluid, which depends a good deal on the fluid's temperature. The allowable temperature range for the science boom's deploy device, for example, is 20° to 30°C.

Several of the science instruments cannot be operated except at low temperature or low pressure. For example, the solid state imaging (SSI) subsystem and near infrared imaging spectrometer (NIMS) operate best at temperatures far below zero. Several instruments contain high voltage devices that can be operated only in a vacuum, to avoid arcing (shorts) that might occur under atmospheric pressure.

"Several design decisions will need to be made based on the test results, but the thermal design is good," concluded Becker. ■

Q&A

Q: The Galileo orbiter is a dual-spin spacecraft—one section spins while the other is mechanically despun. How many rotations is the spun section expected to complete during the mission?

A: Galileo's spun section will rotate over 7 million times in the period between launch in May 1986 through the end of the nominal mission in late 1990. The rotation rates range from 3 to 10 rpm, with the lower rate allowing the fields and particles instruments to sweep the sky and the higher rate providing stabilization for spacecraft maneuvers such as separation of the probe from the spacecraft and all burns of the 400 N engine. When the spacecraft operates at the 3 rpm rate, the despun section will normally be operating at 0 rpm. At the 10 rpm rate the despun section will be "locked" to the spun section.

Q: The term "spacecraft integration" is jargon to the man on the street. Very simply, what does it mean?

A: Spacecraft integration is the process of mechanically and electrically connecting the many individual pieces of the spacecraft. In other words, it means building the spacecraft. As it is built, it is also tested to be sure everything works properly.

Q: Why does the test and integration schedule include a period called "burn-in"?

A: Electronics parts tend to fail early in their lifetime if they contain any defects. During burn-in, the electronics are operated continuously for as many hours as possible to weed out any weak parts before launch. Many of Galileo's electronics parts are new designs using new manufacturing techniques, so burn-in is an essential phase of spacecraft testing. ■

Meet the Team

Neil Ausman, Jr.

"In this business, memory is an absolutely necessary attribute," says Neal Ausman, Jr., manager of Galileo's mission operations and engineering office. "Without it, you're just not able to relate the incredible number of interfaces that characterize the Mission Operations System."

Neal's job encompasses a broad area of responsibility, including development of Galileo's ground and flight software, spacecraft fault protection, design and implementation of the mission support area, operations planning, and interfaces with the Deep Space Network, JPL's Mission Control and Computing Center (MCCC), the Space Transportation System (from an operations viewpoint), and the German Space Operations Center (GSOC) which will help with tracking and data processing during the Earth-to-Jupiter cruise.

Neal came to the project with a firm background in operations, having worked on spacecraft and launch operations at Cape Kennedy, Florida while in the Air Force. Joining JPL in 1967, he managed the old Space Flight Operations Section for 7-1/2 years. A short stint in Voyager operations near launch in 1977 convinced him that he'd like to be directly involved again in operations.

"Galileo is the ultimate challenge for operations—it is the most operationally complex unmanned mission ever conceived, and it was too exciting to pass up!

"Our most important short-term task is completing the development and test of the spacecraft flight software before the spacecraft is shipped to Florida next January. Our biggest operational trial, in the near-term, will be the period immediately after launch when we will characterize the spacecraft's behavior in space. Galileo is the most complex spacecraft ever built at JPL, and we expect to learn a lot about it after launch. Technically, we know what it's supposed to do, but there's sure to be surprises.

"Looking ahead, we will have the equivalent of a Voyager Jupiter encounter about every 30 days during the height of the mission, and the Galileo flight team will have to process all the science and engineering data quickly to use it for future data gathering plans," he concluded.

In addition to his Galileo job, Neal is a professional artist, working in wood sculpture and stained glass. With all the demands on his time, he is still able to complete two to four pieces a year, working on a commission basis. Sports are also a big passion, as he holds season tickets to the Raiders and Dodgers, plays in JPL's softball leagues, and still has time for a little golf.

Several years ago he met an Englishwoman who was vacationing in California, and after an intercontinental romance, Neal and Shelagh married. They now live in Glendale. Neal also has two grown daughters.

"I couldn't write a script that could make my life any nicer or any more exciting," he says, with a smile. ■

A member of the Galileo project staff at JPL, Bill Fawcett is responsible for overall management of the orbiter instruments development effort.

"It's a job with appropriate proportions of challenge and fun," says Bill. "I'm basically a juggler; I juggle budgets, schedules and technical performance and try to keep the frame of reference headed firmly toward launch. Seriously, although the instrument developers bear primary responsibility for instrument functional performance, we share that responsibility with respect to overall system compatibility and we must continually be

Bill Fawcett

searching for and circumventing those traps and pitfalls which can result in less than desirable payload scientific performance. Moreover, because of Galileo's dual spin design and the increased reliance on software for optimal system and subsystem performance, the interaction among system elements is significantly greater than on previous missions. When these challenges are combined with the opportunity to work closely with outstanding teams of investigators and very dedicated instrument support personnel, the job is always exciting and often rewarding. The real reward, though, comes shortly after launch when each instrument is turned on and its telemetry says, 'I'm O.K.' Then we know we've done it right . . . and we're O.K."

Bill studied electrical engineering, earning a B.E.E. from New York University in 1959. After two years at Bell Laboratories, he joined JPL where he has been associated in some manner with science instrument development on every Mariner mission but one, plus Viking, Voyager, and now Galileo.

Bill and his wife, Jeanette, a former JPL secretary, live in Tujunga and have two teenage daughters. When he isn't working at JPL or pulling weeds at home, Bill can usually be found fishing for freshwater bass. ■

Minimum Capability Hybrid Simulator

The MCHS—minimum capability hybrid simulator—is a ground-based system developed by JPL's Spacecraft Data Systems Section to evaluate and test the computer sequences that will operate the Galileo spacecraft.

Engineers and programmers are also using the MCHS to help them develop and debug the software being written for the spacecraft's command and data subsystem (CDS), Galileo's "heart and brain".

After launch, the MCHS will be used to weed out errors in sequences before they are sent to the spacecraft and to analyze problems that may occur in flight.

The MCHS differs from simulation systems used for previous missions in that it is a hybrid of both hardware and software.

The CDS is one of two on-board computer systems that will control the Galileo spacecraft in flight, supported by a battery of computers and people on the ground (known collectively as the Galileo Mission Operations System). The CDS and the attitude and articulation control subsystem (AACS) (the other primary on-board computer) are designed to automate the everyday routine of the spacecraft, high-activity periods of science observations, and several critical "one-chance" tasks such as probe release or Jupiter orbit insertion.

Although the CDS is based on designs for previous spacecraft, it is still a new computer system that must perform unique duties flawlessly. It must be exhaustively tested prior to launch.

"The MCHS exists to help ensure that the spacecraft will do its job," explained Fred Akers, supervisor of the Data Systems Simulation Group. "The spacecraft is a complex, semiautomatic system that has to work right the first time—there won't be a second chance for many of its critical tasks."

The CDS receives commands from Earth, sends these instructions to the appropriate parts of the spacecraft, collects data back from the various spacecraft systems, and returns the data to Earth. Most of the commands are linked into sequences that are stored in CDS memory to automatically operate the spacecraft for periods ranging from several days to several months. The CDS controls on-board telemetry, command handling, spacecraft time maintenance and sequencing operations, fault protection, and data communications among subsystems. The MCHS must simulate these functions during CDS testing.

Based in a laboratory in JPL's Control Systems Laboratory, the MCHS hardware includes a "breadboard" CDS (the developmental electronic circuit boards), a laboratory test set of three minicomputers, and six microprocessor test systems—a total of fifteen computers.

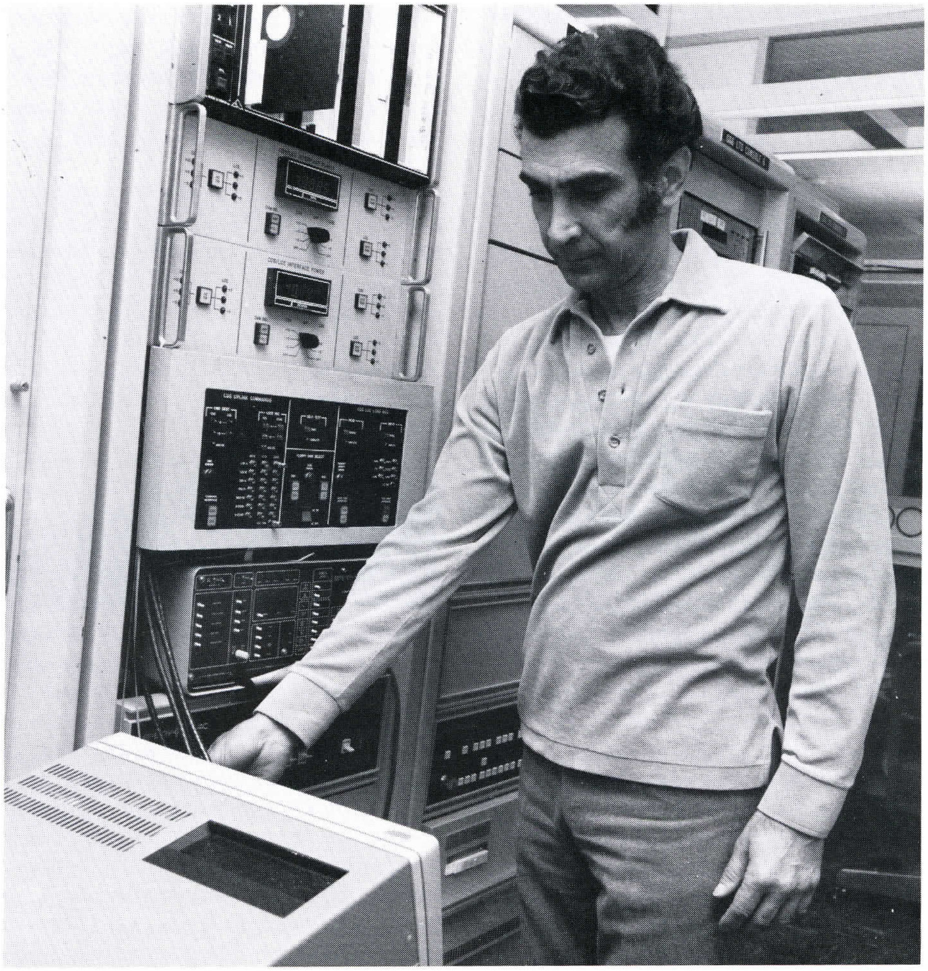
The laboratory test set consists of three minicomputers that control special hardware interfaces with the CDS. This equipment loads and verifies the contents of CDS memories, simulates the uplink command process to the CDS, monitors CDS bus traffic, simulates engineering and science instrument processes, checks times of occurrence of events in the sequences, and monitors telemetry processes.

Six microprocessor test systems direct the internal operation of the microprocessors on the CDS breadboard. These are controlled by MCHS software and special interface hardware. They examine and alter CDS memory and internal CDS storage registers, establish program breakpoints, and execute programs.

The MCHS software consists of a preprocessor, simulator, and postprocessor. The preprocessor sets the stage for the simulation of a sequence by translating, reformatting, and time-ordering input from other areas of the Mission Sequence System. The input includes the simulation test script and selected values for variables such as CDS memory data, initial simulation conditions, ground commands, desired memory word file, spacecraft events, command translator file, spacecraft clock file, one-way light time, cumulative memory map, and spacecraft state file. Once the stage is set, the simulation system executes the test script and monitors the CDS. A history of the test is sent to the postprocessor. The postprocessor decodes, reformats, collects, and saves the simulation data for analysis.

"To a limited extent, the MCHS can make the CDS believe actual

Hardware engineer Chuck Keith uses an oscilloscope to check the CDS breadboard.



events are happening," explains Akers. "For example, it simulates actions of the attitude control system or the digital tape recorder, and analyzes the CDS's response to be sure it acts appropriately. To analyze the simulation, we look at the 'bus traffic'—commands, parameters, and data—and compare it to expected values." (A bus is a circuit over which information from many different sources is sent to many different destinations.)

The development of the MCHS has been phased over several years. It is now being used to test the launch version of flight software and to simulate sequences for final spacecraft testing at JPL. ■

◁ MCHS software cognizant engineer and programmer Cas Sagoian checks a logic analyzer used for troubleshooting.

NASA

National Aeronautics and
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Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

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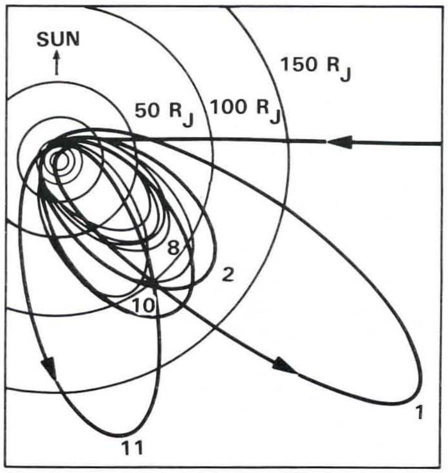
Project Selects Orbital Tour

The Galileo orbiter now has an itinerary. Mission designers and scientists have agreed upon the orbital tour that the spacecraft will take around the moons of Jupiter in 1989 and 1990.

Following the probe mission on December 10, 1988, the orbiter will fire its retropropulsion module (put on the brakes, in other words) to slow itself enough to be captured by Jupiter's gravity and inserted into orbit about the planet.

The first orbit will be the longest with a period of 206 days. Mission operations personnel will track the orbiter for at least 22 months through 10 orbits of Jupiter, targeting a close flyby of one of Jupiter's large moons, Europa, Ganymede, or Callisto, on each orbit. A bonus will be a "non-targeted" encounter with one of these satellites on five of the orbits.



The Galileo orbiter will make 10 orbits of Jupiter in 22 months from 1988 through 1990.

"The difference between targeted and non-targeted encounters is in how they are handled in mission operations. For targeted flybys, spacecraft propellant will be used to perform maneuvers to target the spacecraft for a very accurately controlled and usually very close flyby of a specific satellite. The encounter conditions for a non-targeted flyby, however, are determined from the resulting trajectory with no propellant expended to directly control them. The non-targeted encounters will still be very close in terms of any previous spacecraft flybys, and are just as important as the targeted flybys since they provide valuable global coverage of the satellite," explains Lou D'Amario of the tour design team.

The spacecraft will fly about 1000 km above the surface of Io about four hours before the probe enters Jupiter's atmosphere. The radiation exposure is very high that close to Jupiter, so this will be the only Io flyby of the Galileo tour. Distant observations of Io may be conducted during the orbital tour.

Between satellite observations, the orbiter will observe the planet and measure the magnetosphere. The new tour design affords better opportunities for Jupiter atmospheric measurements than did any previous tours.

The selected tour design is the result of several years of work to squeeze the most science observation opportunities into a very

— *see page 7*

From the Project Manager

On November 1, the Project will enter a new stage, beginning the transition from the development and test phase to the launch and flight operations phases. Development of computer sequences for the early cruise stage of the flight to Jupiter will begin on November 1.

The personnel who are currently completing test operations are also among those who designed the spacecraft and who will, in subsequent operations phases, operate the spacecraft during launch, cruise, and planetary operations.

The launch operations organization will be operative during the period from shipment of the spacecraft to the launch complex (January 1986) through the first two months following launch. The cruise operations organization will be operative from launch plus sixty days (roughly July 1986) until 180 days (about June 1988) before the spacecraft begins its orbital tour at Jupiter. The final organizational structure will then be activated and will manage the planetary operations through the end of the project, now planned for early 1991.

Some key staff members will continue to serve in the same positions; others will ease into new jobs on the project; and still others will be formally appointed to jobs they filled in an acting capacity. One notable change is the assignment of Jim Pollack of Ames Research Center to the role of Probe Scientist while Larry Colin of Ames spends a school year at Stanford University. □

— *J. R. Casani*

Shuttle Crew Visits JPL

Galileo project manager John Casani briefs Galileo commander David Walker, mission specialist John Fabian, and Ulysses commander Rick Hauck in JPL's Spacecraft Assembly Facility.

On Monday, August 12, two critical elements of the Galileo mission were delivered to JPL. These two components were not, however, made of metal or synthetics. The elements were two of the four crew members for STS Mission 61-G – the Galileo launch.

Commander David M. Walker and mission specialist John M. Fabian spent the day touring a number of JPL's facilities, meeting with upper-level management, and speaking to the members of the Galileo Project staff. In addition, Walker and Fabian were joined by Commander Rick Hauck of the Ulysses Mission (STS 61-F).

Both Walker and Fabian agreed that the Galileo launch is the most important of the interplanetary missions NASA is flying. Said John Fabian, ''This flight is at the top of the mission list in terms of priorities. We feel very honored to have been selected as crew members.''

Galileo couldn't be in better hands, either. Fabian is the most experienced of all the Shuttle mission specialists — especially in the area of satellite/payload deployment.

When asked what the most satisfying part of a Shuttle mission was, the crew of 61-G had similar responses: ''It's the feeling of a job well done,'' intoned the lanky Fabian. David Walker agreed in saying that, ''The accomplishment of all the assigned tasks of a particular mission is very satisfying.''

The two other members of the crew of 61-G were unable to visit JPL on this trip, as they were both training for near-term future missions. Ronald Grabe, the pilot for the Galileo mission, was in training for the maiden flight of Atlantis (Galileo's orbiter) coming up in October 1985. James ''Ox'' van Hoften was also busy, preparing himself for Mission 51-I, in August, when he and William Fisher went outside the Shuttle to repair the Hughes Leasat Syncom IV-3 satellite deployed from the Shuttle last April. The satellite was deployed successfully from Discovery, but failed to activate itself once free of the cargo bay.

When asked what the most exciting part of a Shuttle mission was, David Walker replied that the re-entry and landing were the best portions of the flight.

In contrast, Rick Hauck said that the ascent into orbit and the magnificent view from space was the most exhilarating part of being a Shuttle astronaut. Hauck's answer is not out of character. When asked earlier why he decided to become an astronaut, Rick replied with his typical keen sense of wit, ''I always liked to go fast.'' □

— J. Harris

Spin Bearing Assembly

The Galileo orbiter is a ''dual-spin'' spacecraft — a spinning section will allow instruments to measure fields and particles in space while a despun (nonspinning) section will provide a stable platform for the camera and other remote sensing instruments. These two sections are mechanically connected by a device known as the spin bearing assembly (SBA) and electrical signals are passed between the two sections via the SBA.

The spin bearing assembly was functionally tested on the flight spacecraft last spring in JPL's Spacecraft Assembly Facility. The purpose of the test was to check mechanical clearances between the spun and despun sections and to allow the spin bearing assembly to dynamically operate and flow signals and power across the spinning slip ring and rotary transformer interfaces.

The orbiter was raised into the air until it was hanging about 20 inches above the work stands, and then, after carefully separating the joint between the spinning and nonspinning sections of the spacecraft and checking clearances, commands were sent to the SBA to initiate the spinning motion. For this test, the spun section was held stationary while the despun section rotated at about 3 revolutions per minute.

In flight, the spacecraft will operate in several modes: inertial, cruise, and all-spin at rates from 3 to 10 rpm for stabilization. The entire spacecraft will

use the higher spin rate in all-spin during probe release, the orbit deflection maneuver, Jupiter orbit insertion, and the perijove raise manuever. During the normally quiet cruise mode and the high performance inertial mode, only the spacecraft's spinning section will rotate.

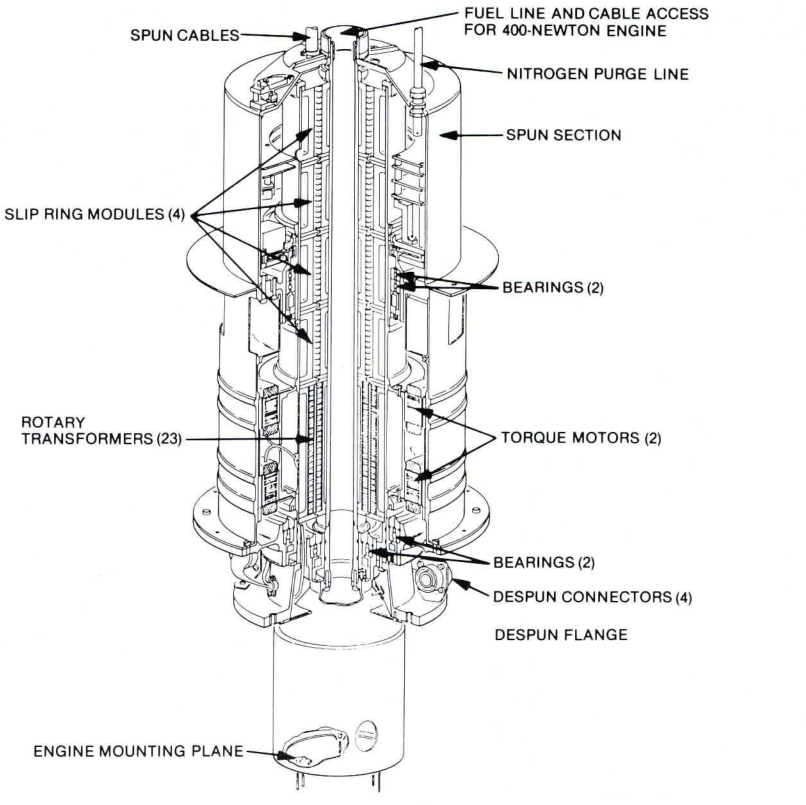
The design of the SBA presented a unique challenge in transferring power and data between the two parts of the orbiter. Since one part spins with respect to the other, cables could not be used since they would become wrapped around the joint that connects the two parts. The solution is twofold: power and low data rates will be transmitted via 48 slip rings, while high rate data will be transmitted through 23 rotary transformers (see cutaway drawing).

"In the slip rings, a flexible brush contact rides on a large revolving ring that is electrically connected to the spinning side," explains Garry Burdick, assistant manager of JPL's Guidance and Control Section. "The rotary transformers consist of pairs of coiled wires around a ferrite core. One coil is electrically connected to the spun section and the other to the despun section. Signals are transmitted without contact by means of the magnetic field generated by pulses of current in the coils."

The relative rotational position between the spun and despun sections is continuously measured and derived from an optical encoder within the SBA. The SBA is controlled by the attitude and articulation control subsystem (AACS) onboard the Orbiter.

"Galileo's configuration is unique in that the 400-Newton main engine, which is rigidly attached to the spinning section, is located within the envelope of the despun section," notes Frank Locatell, cognizant engineer for the configuration of the SBA and despun section. "Thus, the spun propellant lines and engine cables are routed through the center of the SBA. This is the first configuration of this kind."

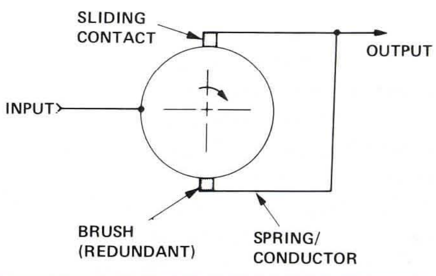
A significant number of glitches and noise interfered with the electrical signals of two slip



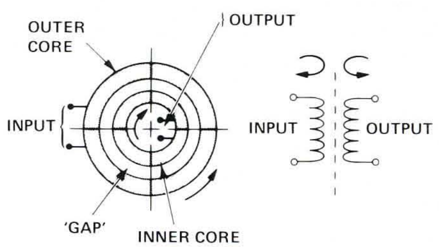
Cross section of Galileo's spin bearing assembly shows major elements.

ring modules during life tests begun last year. Similar problems were found with the flight SBA this spring. Such interference could have been troublesome for the mission. After an intensive effort (headed by Joe Savino of JPL's Electronics and Control Systems Division) to determine the cause of the problem and appropriate action, the flight SBA was disassembled, inspected, analyzed for contamination, retrofitted with new slip ring modules, wired, and reassembled. Since the voltage transients were most probably caused by chemical contamination accumulated during the building process, the SBA has been rebuilt with extremely clean components and internal redundancy has been re-apportioned to provide more system immunity to this type of electrical noise. In addition, system modifications were made to assure that the spacecraft would be less sensitive to noise. The rebuilt SBA is being delivered to JPL's Spacecraft Assembly Facility in September 1985 following performance checks and functional tests.

At launch, the spun and despun sections will be rigidly held



Slip rings will transfer power and low-rate data.



Rotary transformers will transfer high-rate data.

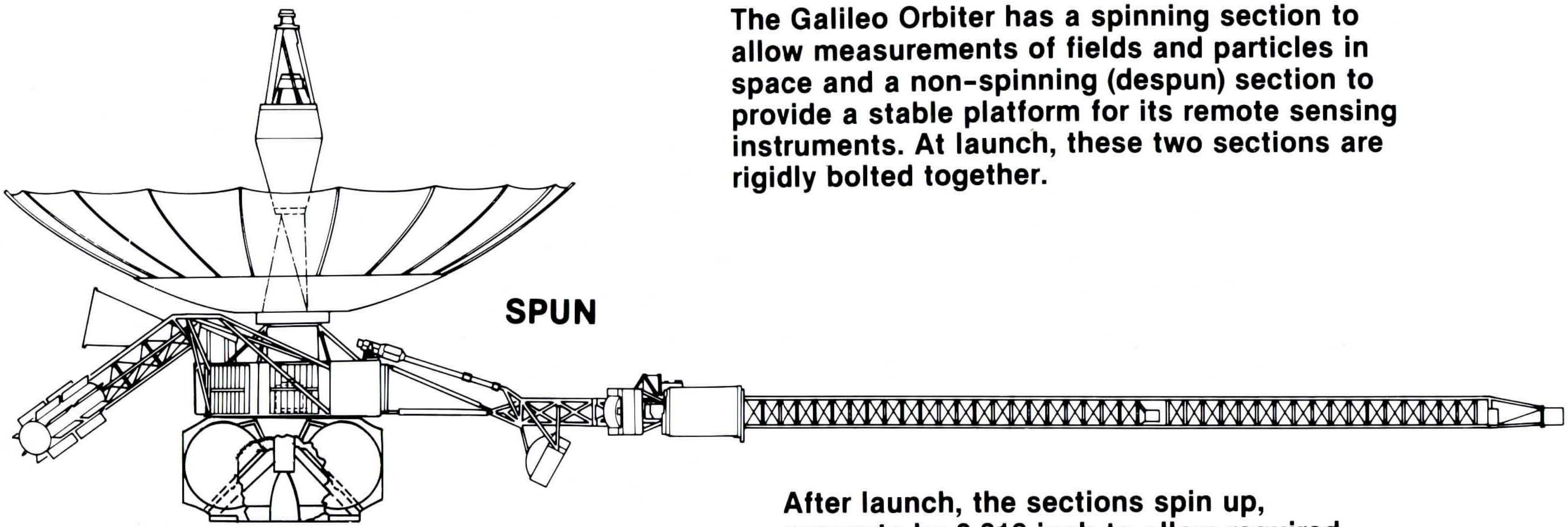
together. After launch, the sections will be separated and remain separated for the duration of the mission. The centerfold drawing describes the separation joints and mechanisms.

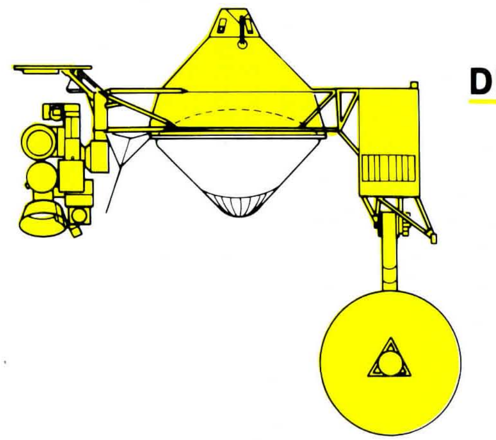
A discussion of the SBA power/data transfer design appeared in Issue 1 of *The Galileo Messenger*, April 10, 1981. □

Separation of Galileo Orbiter Spun / Despun Sections

Separation Joints and Mechanisms

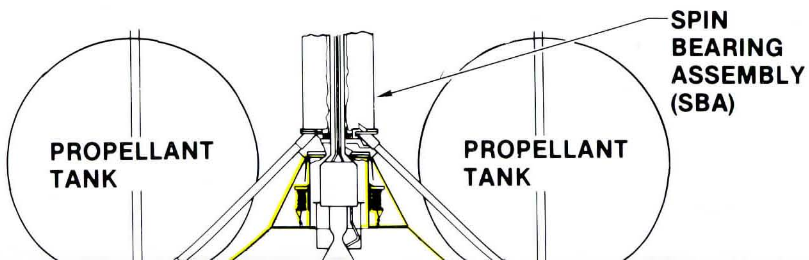
The Galileo Orbiter has a spinning section to allow measurements of fields and particles in space and a non-spinning (despun) section to provide a stable platform for its remote sensing instruments. At launch, these two sections are rigidly bolted together.



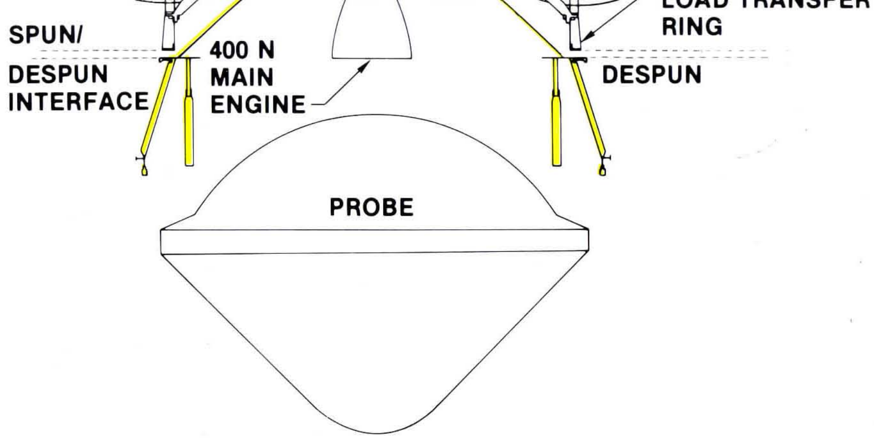


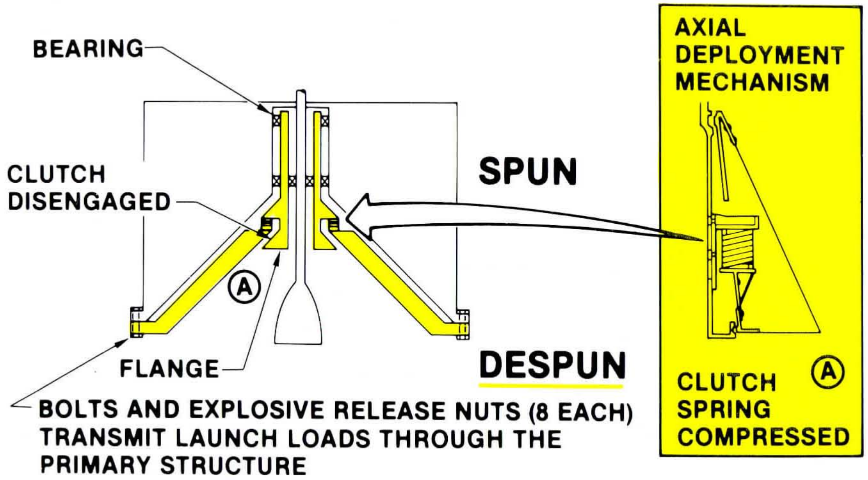
FLIGHT CONFIGURATION
(SEPARATION GREATLY EXAGGERATED)

After launch, the sections spin up, separate by 0.312 inch to allow required clearances for relative rotation, and remain separated for the duration of the mission.

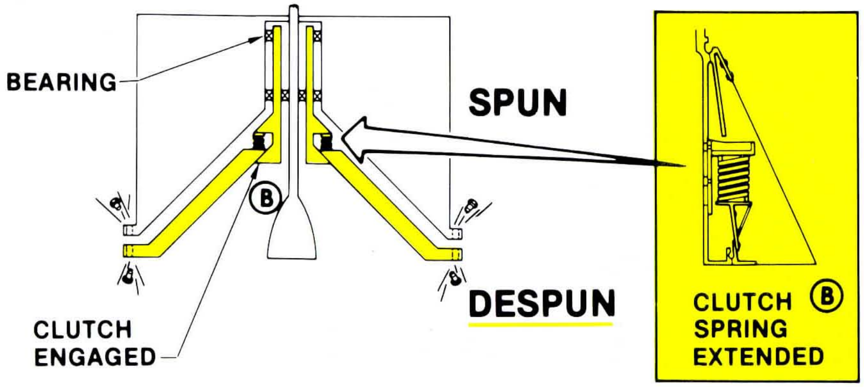


The spin bearing assembly mechanically couples the two parts of the orbiter. Its motor is used to counterrotate the despun section. Electrical signals are transferred across the interface by means of slip rings and rotary transformers. This interface is further complicated by the central location of the main engine and its plumbing lines.





At launch, the spin bearing assembly is connected to the despun structure through four clutch engagement springs only, effectively isolating launch loads from the bearing assembly. The clutch springs are compressed and the clutch is disengaged.

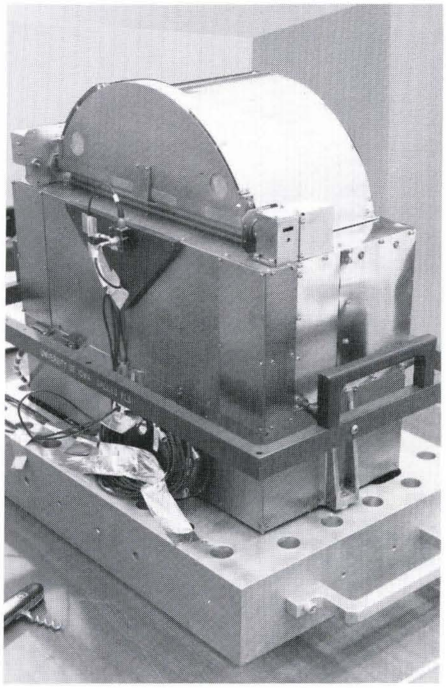


At separation, the bolts and explosive nuts are released, the springs extend, and the clutch engages. The spin bearing assembly becomes rigidly coupled to the despun support structure.

Plasma Investigation

An orange glow, reminding me of a blow torch flame in size and intensity, shimmered inside the glass tubing in a chemistry lab. "That's a plasma," said my friend, the chemist. "But there are lots of different types of plasmas," he cautioned.

Nonetheless, having seen that small bit of created plasma helps me relate a little better to the complexity of studying natural plasmas in space.



Plasma instrument

A plasma is a collection of charged particles, usually made up of about equal numbers of ions and electrons. In some respects, plasmas act like gases; but, unlike gases, they are good electrical conductors and are affected by magnetic fields.

Galileo's plasma subsystem is designed to determine the properties of low-energy plasmas throughout Jupiter's magnetosphere, including plasma temperatures, densities, bulk motions, and composition. Observations by the Pioneer and Voyager spacecraft revealed that Jupiter's magnetosphere is a large and complex reservoir of charged particles. Building on the information provided by its forerunners, Galileo has the advantages of a spinning section that will allow all-sky observations of fields and particles, a flexible command system, and long-term observations as the spacecraft orbits Jupiter for at least 22 months. The plasma instrument is also an advance over previous systems, with an extended sensitivity range for measuring electrons and positive ions, improved temporal resolution, and the ability to identify the composition of ions.

Jupiter's magnetosphere is of special interest for several reasons. It is the largest single object within the solar system, with an average diameter of about 15 million kilometers. If it could be seen from Earth — about 440 million miles away — it would occupy 1.5 degrees of sky, compared to the Sun's 0.5 degrees of sky. In addition, Jupiter's rapid rotation creates a magnetosphere that resembles a pulsar, although much weaker.

Three ion sources have been identified for the plasma in Jupiter's magnetosphere: the Sun, the planet's ionosphere, and the large satellites. In the outer magnetosphere (beyond 60 Jupiter radii), the ions of helium, carbon, nitrogen, oxygen, neon, manganese, silicon, and iron probably originate from the solar wind. Closer to Jupiter, the ions of sulfur, sodium, and oxygen probably originate from Io and its dense plasma torus. Energetic molecular hydrogen most likely comes from the ionosphere.

Galileo's plasma instrument has two electrostatic analyzers that measure the energy per unit charge for electron and positive ion intensities both separately and simultaneously. They also measure the direction of flow of the charged particles. Each of the plasma analyzers is powered and programmed separately.

In addition, three miniature mass spectrometers measure the mass per unit charge of positive ions. Since neither Pioneer nor Voyager carried such spectrometers, Galileo will provide the first direct identification of ion species.

The overall field of view is fan-shaped, with seven aperture slits for the plasma analyzers' sensors. The fields of view for the mass spectrometers are positioned near the exit apertures of the plasma analyzers. The fan-shaped field of view is rotated about the spacecraft's spin axis during all-sky surveys to determine the directional flow and velocity of the charged particles.

Lou Frank

The range of the plasma analyzer is 1 to 50,000 volts, compared to 100 to 4800 V for the Pioneer spacecraft and 10 to 5920 V for the Voyager spacecraft. In addition, Galileo's temporal resolution is 5 seconds, compared to 200 seconds for Pioneer's ion analyzer and Voyager's Faraday cup. These improved resolutions are important for the fast flybys of the satellites and crossings through various plasma areas.

Principal investigator for the plasma subsystem is Lou Frank of the University of Iowa. □

— A. Sohus

Meet the Team

Scholar, humanist, romantic — Sanford Jones likes to think he would have had a little in common with the great Renaissance scholar and satirist Erasmus.

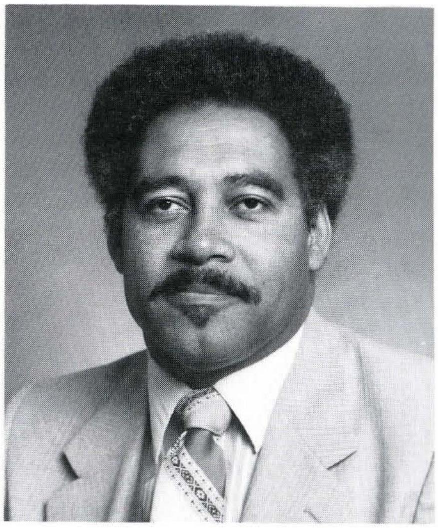
As manager of the Galileo orbiter, Sanford coordinates activities between the project and the technical divisions at JPL, making sure the hardware is delivered to the spacecraft. He controls the resources — money, schedules, and workforce — for the Galileo tasks of the technical divisions.

Sanford came to Galileo — and to JPL — in 1978 as assistant orbiter manager.

"There is a degree of thoroughness at JPL that is not present in industry, primarily because here we are making only one of a product, not thousands, and it must be perfect," he notes. "I'm not sure everyone appreciates what a valuable commodity there is in the knowledge and experience of the people who work on our space missions," he remarks.

A native of Atlanta, Georgia, Sanford earned his undergraduate degree in physics at Case Institute of Technology, did graduate-level work in subjects ranging from contract management to quantum mechanics, and pursued a doctorate in macroeconomics at Cleveland State University.

"I like science fiction, and I'm working in a field that's as close to science fiction as I can get — its where I'm happiest, and I appreciate being paid to do what I like!" he declares.



Sanford Jones

Father of four and grandfather of one, he also is a talented landscape photographer. Currently remodelling and landscaping a 1910 house in nearby Eagle Rock, he is planning to add a darkroom, oak-panelled library with brass fittings, a gazebo, and herb garden — the kinds of things one might find in a romantic Old English country house.

Civic activities are also important to him and he is active in church work locally and at the district level of his denomination. He is also chairman of the board of directors of a development company of the Southern California Urban Coalition. □

Project Selects Orbital Tour

(continued from page 1)

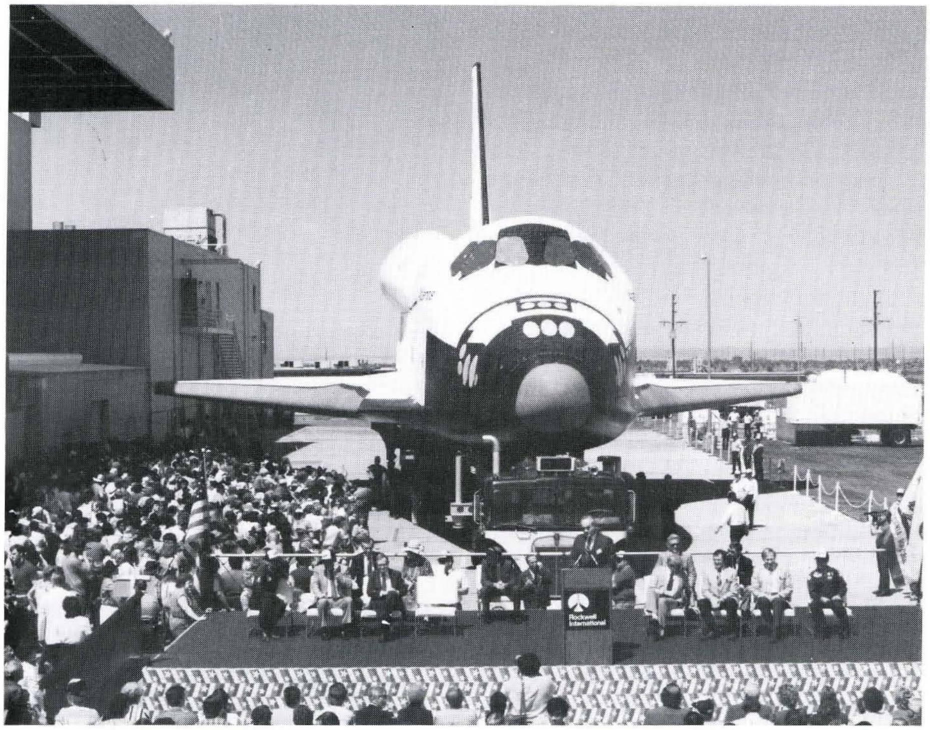
efficient (in terms of propellant usage) flight path. Many orbital tours have been designed since the project began, but changes in the mission necessitated tour redesigns. The selected tour was one of about a dozen designed after Galileo's path to Jupiter was changed to provide an opportunity to observe the asteroid Amphitrite about six months after launch. This Earth-to-Jupiter trajectory delays the arrival at Jupiter by a little over three months from previous plans, and necessitated the new tour design.

Members of the tour design team include Roger Diehl, leader; Jim Longuski and Aron Wolf, tour design; and Dennis Byrnes and Lou D'Amario, tour optimization (minimizing the total propellant required). All are in JPL's Mission Design Section. □

Galileo's Satellite Encounters at Jupiter

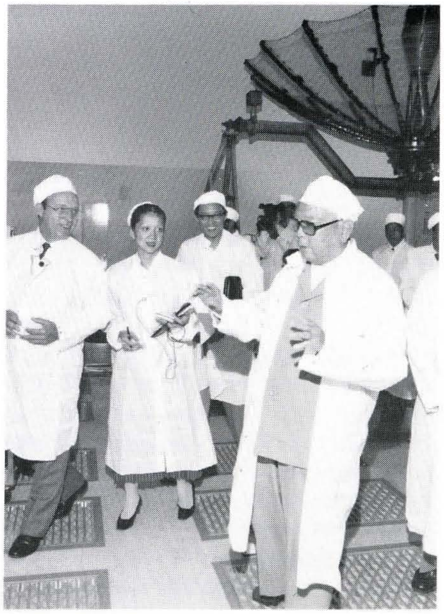
Encounter	Date	Satellite/ Inbound or Outbound	Altitude (km)	Latitude (deg)
1	3 Jul '89	Ganymede/in	828	-15
2	5 Sep '89	Ganymede/in	863	-80
3	29 Oct '89	Callisto/in	1,392	-4
3*	31 Oct '89	Europa/in	136,859	2
4	9 Dec '89	Europa/in	291	-4
4*	11 Dec '89	Ganymede/out	25,000	7
5*	8 Jan '90	Europa/out	48,016	-4
5	8 Jan '90	Ganymede/out	6,350	23
6	12 Feb '90	Europa/out	1,425	70
7	19 Mar '90	Europa/out	200	-74
8	22 Apr '90	Ganymede/in	900	-19
8*	25 Apr '90	Callisto/out	25,004	0
9	1 Jul '90	Callisto/out	1,631	-15
10	14 Aug '90	Ganymede/in	458	-17
10*	15 Aug '90	Europa/in	24,872	31
Tail Petal Apojove	11 Oct '90			

**Non-targeted*

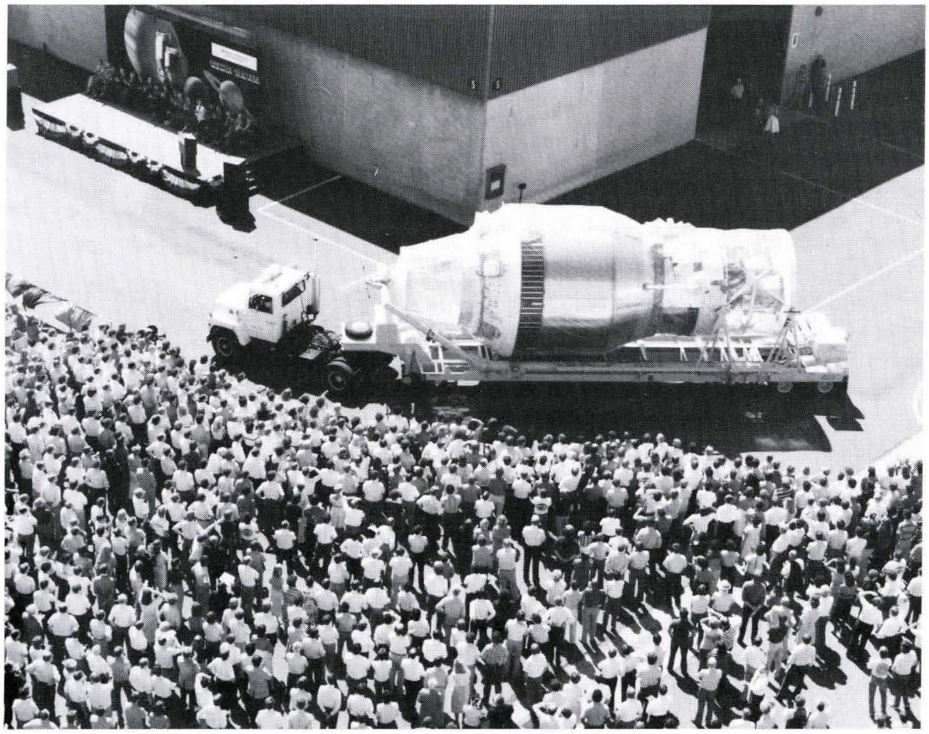


Rockwell International

Space shuttle orbiter Atlantis, which will carry the Galileo spacecraft and Centaur upper stage to low-Earth orbit, rolled out at Rockwell International's Palmdale, CA, plant in April 1985. The Galileo mission will be its third flight.



Li Xiannian (right), President of the People's Republic of China, expresses delight while touring the Spacecraft Assembly Facility with his entourage and project manager John Casani (left).



General Dynamics/Convair

Crowds of employees gathered at General Dynamics/Convair factory in San Diego on August 13 to view the rollout ceremonies for the Centaur G-Prime upper stage. Two of these Centaurs have been built to boost the Galileo and Ulysses spacecraft from low-Earth orbit into interplanetary flight paths.

Quality assurance engineer Eugene Poyorena (left) watches as Dennis Maciej checks clearances and access to the orbiter's propellant tanks during a recent dry run of fuel loading procedures.

Editor .... Anita Sohus
Project Information Coordinator .... Joel Harris

NASA

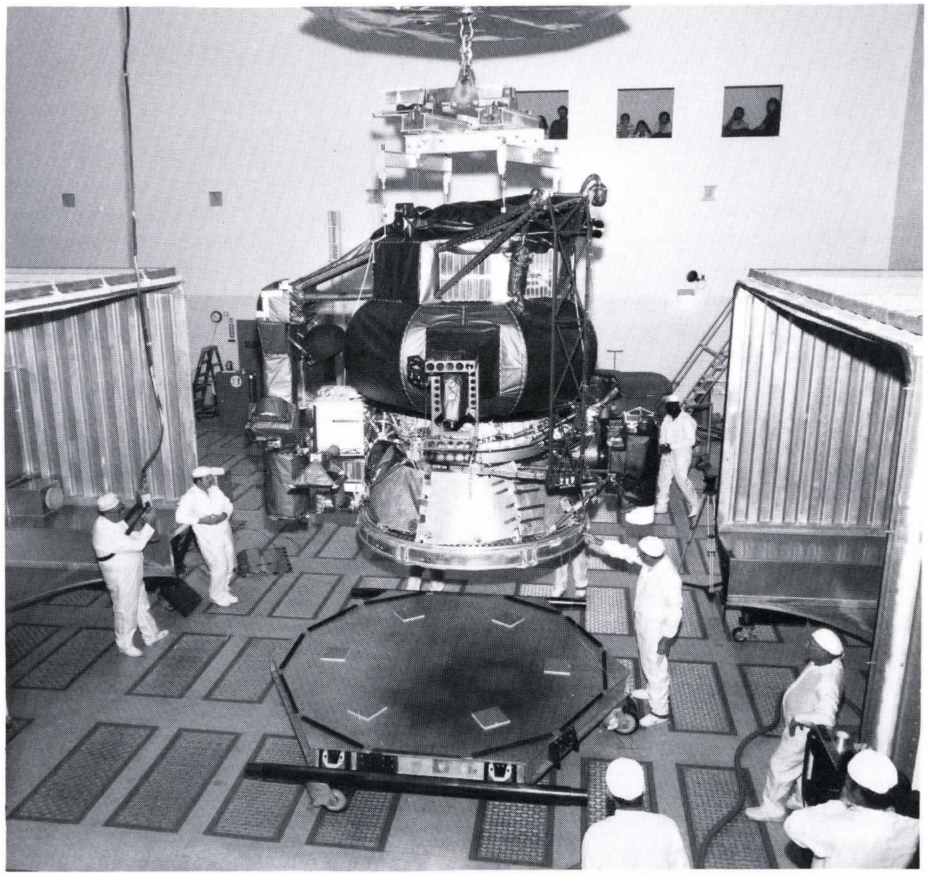
National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

JPL 410-16-14

The Galileo Messenger

Issue 15 **February 1986**



The Galileo spacecraft (minus the high-gain antenna) was hoisted onto a platform and then the "clamshell" shipping container was closed around it.

With its precious cargo in place on a drop-bed trailer, the convoy left JPL in the early morning hours of December 19 and arrived at Kennedy Space Center, Florida, 75-1/2 hours later, on December 22. Other spacecraft hardware and support equipment also travelled in convoys to the Cape.

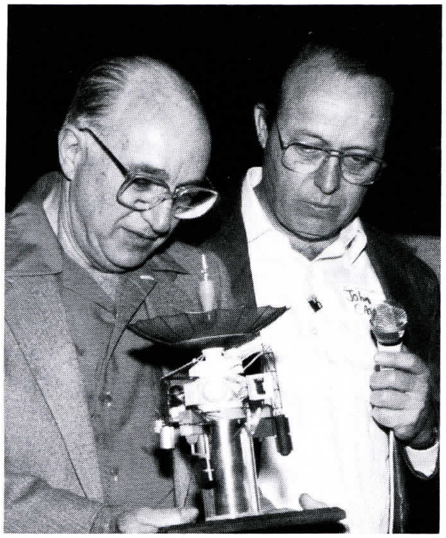
From the Project Manager

We have been informed this week (February 12) that the planetary missions will not be launched in May this year, and that both Galileo and Ulysses have been directed to work toward the next Jupiter launch opportunity, which is in June 1987.

I am pleased that this direction came as quickly as it did, after the tragedy of the *Challenger* mission. The accident was a terrible experience for those personally involved—certainly the families and friends of the crew, but also all of the dedicated people who have worked so diligently and so hard to make the national Space Transportation System a reality. We at JPL have been deeply moved by the experience, and we share, as does the rest of the nation, in the sorrow and personal loss of those involved.

It is gratifying to see how quickly Jesse Moore's team and the Presidential Commission have been established, and how vigorously they are working to find out what happened, why it happened, and to determine what must be done to assure that it will not happen again. We can be confident that our space program will be back on track quickly.

In December, we celebrated shipment of the Galileo orbiter and probe to the launch center in Florida. We are planning to continue with spacecraft testing and integration and to go as far as we can, including mating the spacecraft to the Centaur upper stage in Kennedy Space Center's Vertical Processing Facility (VPF),



Galileo's Chief of Test and Operations Milt Goldfine (left) won a scale model of the spacecraft as top door prize at the pre-ship party on December 13. Project Manager John Casani looks on.

and hopefully continuing with operations through the integrated wet (propellant loaded) Countdown Demonstration Test on Pad 39 with the Centaur and the shuttle orbiter *Atlantis.*

Current plans are to leave the spacecraft at the Cape in "active storage," that is, in a condition that will allow us to continue to test it during the next year. This will mean sending selected support equipment from Pasadena to establish a test environment at KSC similar to JPL's Spacecraft Assembly Facility (SAF) environment.

In the near term we will complete ground data system testing, as well as some mission operations system test and training activities—specifically, one launch exercise and one trajectory correction maneuver exercise. We will complete the design work for the early months of the cruise to Jupiter, continue to prepare flight team procedures, and continue contingency planning.

The mission design people will be busy defining new targeting specifications, selecting the new Jupiter arrival date, and establishing a new design for the orbital tour of Jupiter's satellites. The earliest possible Jupiter arrival date will overlap with Voyager 2's Neptune observations in late summer of 1989, so we may be forced to select an arrival date a little later than that. Much depends on the scheduling of the Deep Space Network's tracking coverage.

Of course, the opportunity to study the asteroid 29 Amphitrite was lost when the May 1986 launch was cancelled. The trajectory designers will be looking for other opportunities to study an asteroid, but it is unlikely that another asteroid as large, as accessible, and as scientifically interesting will be found in the new trajectory.

There has been a lot of speculation on what would have happened had Galileo and its Centaur upper stage been onboard the *Challenger*. It won't be possible to analytically assess that until the data from the accident is available. However, based on the limited data that is available, expert opinion indicates that the explosion and fire were of an intensity far below the levels that the radioisotope thermoelectric generators are designed to withstand.

The House Committee on Science and Technology, chaired by Congressman Don Fuqua (D-FL), visited JPL this week to assess the impact of the Challenger accident on planetary programs, and I am encouraged by the continuing Congressional support of the planetary programs.

NASA is moving forward with plans to modify another shuttle, most likely the *Discovery*, to carry the Centaur. This is essential if both Ulysses and Galileo are to be launched in 1987.

The *Challenger* accident was a tragedy of great human dimension, touching not only the lives of those personally involved, but the entire nation as well. It will certainly affect the space program but it will not stop it. The problem will be resolved and the program will go on. We on the Galileo team must press on with our own challenge: the successful execution of a scientifically rich and fascinating mission of discovery at Jupiter. □

— J.R. Casani

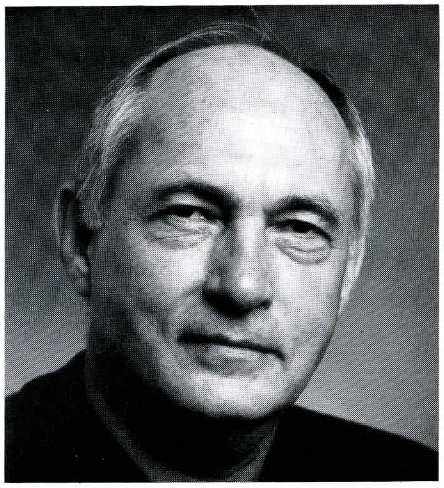
(ed. note: Jesse Moore was the NASA Associate Administrator for Space Flight until he recently assumed the directorship of NASA's Johnson Space Center in Houston, Texas.)

Meet the Team

"For me, the most exciting aspect of my job is the actualization: turning concepts into hardware," says Frank Locatell, test and operations engineer for JPL's Mechanical and Chemical Systems Division. "And the interactions with the people rank right up there, too. This is an exciting community to work in."

Upon meeting Frank, one very soon becomes aware of the intensity and enthusiasm he brings to everything he does. Whether designing hardware or training crews on safe handling procedures for critical hardware, he is articulate and focused.

A member of JPL's System Integration Section, Frank is responsible for all support from his division to the Galileo test and operations activities. He is the cognizant engineer for the Super*Zip separation joint between the spacecraft and the Centaur upper stage, for the launch vehicle adapter structures, and for the interface with the retro-propulsion module. He is also responsible for the conceptual design of the despun section of



Frank Locatell

the spacecraft and for the configuration design of the spin bearing assembly.

A native Californian, Frank grew up in the Napa wine country and is a product of the University of California at Berkeley during the turbulent '60's. He holds a master's degree in science and engineering.

Frank and his wife Debbie (who is lead secretary in the Galileo project office) live in a craftsman home in nearby Altadena. They both meditate and practice yoga, and enjoy poking around archaeological sites in southern Mexico and Central America. Frank also hopes to teach and write. □

Q&A

Q: Since the launch scheduled for May 1986 has been cancelled, why must Galileo wait thirteen months for another launch opportunity?

A: Due to the relative motions of Earth and Jupiter, opportunities to launch directly to Jupiter exist only when Earth and Jupiter are in approximately fixed positions relative to each other. However, Earth takes one year to orbit the Sun, while Jupiter completes its orbit once every 12 years. Therefore, the Earth must complete one full orbit plus the same angular distance Jupiter has travelled (one-twelfth of its orbital path) before the planets will be properly aligned again for a direct flight from Earth to Jupiter. Galileo's next launch opportunity will be in late June 1987.

Q: In light of the Shuttle 51-L accident, are there other options available to lift Galileo and its Centaur G′ upper stage into low-Earth orbit?

A: No other system exists that is immediately available to lift Galileo and the Centaur into orbit. While future, expendable boosters (like the Titan III-D-7) are being developed, these will not be available until at least 1990. Galileo and the Centaur were specifically designed to be compatible with the Shuttle. □

Energetic Particle Detector

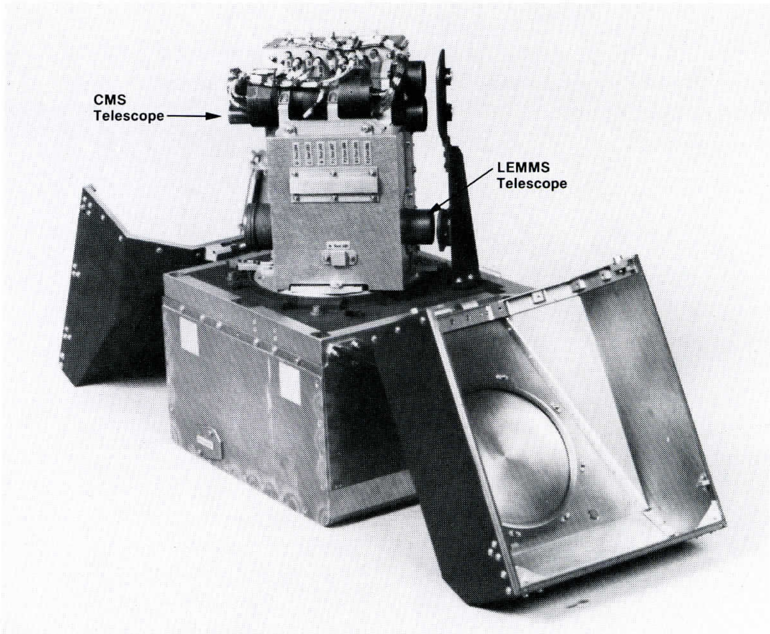
Jupiter's magnetosphere is the region within which the planet's magnetic field and charged particle population is confined by the flowing solar wind. Energetic particle charges are so intense in this region that careful design is required to protect the spacecraft against radiation damage, a particular concern for Galileo which must operate in this environment for its 22-month prime mission.

An immense and dynamic reservoir of energetic particles must be continually replenished to replace those particles which escape into interplanetary space. The processes responsible for this remarkable replenishment are unknown. Coupled with the study of magnetospheric dynamics, the identification of these processes represents the primary focus of Galileo's Energetic Particles Detector (EPD). The EPD measures the composition, intensity, energy, and angular distribution of charged particles (with energies greater than approximately 20 kiloelectron volts) within the Jovian magnetosphere.

Voyager's observations have led to the identification of three sources for Jupiter's energetic particles: the Sun, the Jovian ionosphere, and the Jovian moons.

The Sun (solar wind and energetic particles) is the most likely candidate for the helium, carbon, nitrogen, oxygen, neon, magnesium, silicon, and iron seen in the outer magnetosphere. Closer to the planet, the high abundances of sulphur, sodium, and oxygen provide strong evidence that these particles originate from Io and its plasma torus (a region containing about equal numbers of positively and negatively charged particles). Of the molecular ions observed in Jupiter's magnetosphere, hydrogen (H_2) may come from both the ionosphere and the moons, whereas H_3 is most likely of ionospheric origin. Jupiter's intense proton population probably comes from both the Sun and the ionosphere.

A comparison of Voyager 1 and 2 data strongly suggests that the relative contribution of Jovian and solar sources varies considerably with time. Thus, obtaining a long history of the Jovian energetic particle population is crucial to beginning a study of the dynamics of the Jovian magnetosphere.



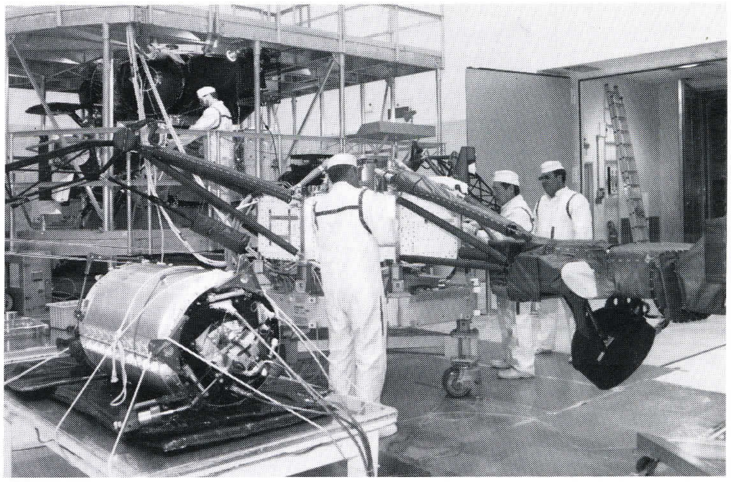
Hinged covers will protect the energetic particle detector before launch.

The EPD uses two silicon solid-state detector systems: the Low Energy Magnetic Measurement System (LEMMS) and the Composition Measurement Subsystem (CMS). The magnetically focused LEMMS separately measures ions and electrons. The CMS uses a multiparameter detection technique to measure ions ranging from protons to iron (an energy range from 80 to 10,000 kiloelectron volts per atomic mass unit). The CMS also determines the velocity of these ions by measuring the time it takes to pass between the front and the back detectors, a distance of 7.5 centimeters (3 inches). This added capability allows a separate check on data validity, which is particularly helpful for particles at high incoming rates.

The detector assemblies use magnetic deflection, absorber materials to differentiate between incoming particle types, and varying aperture sizes to allow operation over a wide dynamic rate range. Radioactive calibration sources are mounted on a vertical shield that is observed by the detectors every 140 seconds.

The primary new thrust to be gained from Galileo will be an understanding of the Jovian magnetosphere and its dynamics. Unlike Pioneer and Voyager, Galileo will be placed into orbit around Jupiter and will obtain (for the first time) continuous coverage of the Jovian magnetospheric particle and field environment. Thus, it will be possible to determine characteristic time variations of the Jovian magnetosphere.

D.J. Williams



Work is underway for final integration and checkout at Kennedy Space Center.

The Galileo mission also affords a much larger coverage of the Jovian magnetosphere, including the important midnight meridian region of the Jovian magnetic tail. The extended coverage will detect how and how much of Jupiter's particle population is lost to interplanetary space.

In addition, the Galileo spacecraft will be maneuvered to perform a total of 10 flybys of Jupiter's four largest satellites, ranging in altitude from a few hundred to a few thousand kilometers. From these close flybys, scientists will determine how the satellites interact with Jupiter's magnetospheric plasma and how this affected the evolution of these bodies.

Finally, the EPD will create a three-dimensional "map" of the energetic particle distribution by rotating through 225° over seven Galileo spin periods (140 seconds). These data will yield information on particle energization and transport, the magnetic field configuration, and particle output from the satellites. Because the ranges of several instruments overlap, Galileo will provide the first continuous spectral observations of the overall Jovian charged particle distribution.

Jim Willett, the EPD science coordinator at JPL, emphasizes, "each of the fields and particles (F&P) instruments senses only a portion of the whole picture. By combining the results of all the F&P instruments we will be able to more exactly shape our model of the Jovian system." The EPD science team also includes The Johns Hopkins University, the Max-Planck-Institut für Aeronomie, the University of Alaska, the University of Kansas, and Bell Laboratories. The principal investigator for the EPD is D.J. Williams of The Johns Hopkins University.

The new dimensions of the Galileo mission may solve the many mysteries raised by the Pioneer and Voyager flyby missions. What are the intrinsic time variations of the Jovian magnetosphere? How do the charged particles escape? What physical processes maintain the intense particle populations in this vast but porous energetic particle reservoir? Are such powerful energization processes universally common? Do these processes sustain a Jovian magnetospheric wind of charged particles flowing away from the planet? Does the interaction of the Galilean satellites with the Jovian magnetosphere affect or guide their evolution? The Galileo mission gives us our best (and for the foreseeable future, the only) opportunity to answer these and other basic questions on the behavior of plasmas in the solar system. □

— J. Collins

NASA

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

JPL 410-16-15 2/86

The Galileo Messenger

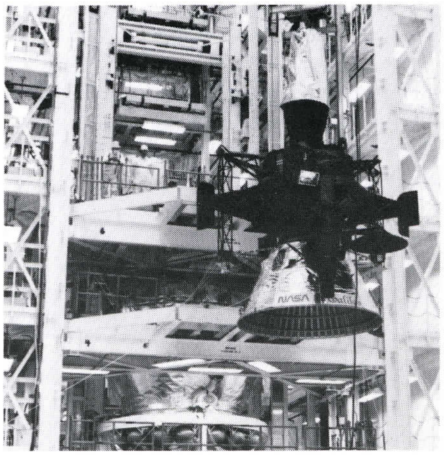
Issue 16 **July 1986**

From the Project Manager

NASA has cancelled the shuttle/Centaur program because of safety concerns with the liquid propellant in the Centaur. The next shuttle launch opportunity for the Galileo spacecraft is December 1989. This option, however, requires development of an upper stage for use with the shuttle.

One possibility would be a two-stage inertial upper stage (IUS) plus an injection module, containing only solid propellant. The planetary alignment at that time will result in a journey to Jupiter lasting 4 years and 10 months. The spacecraft, on a ΔVEGA trajectory, will circle the Sun and fly past the Earth in November 1991, using the Earth's gravity to gain the energy to travel on to Jupiter, arriving about September 1994. The ΔVEGA, an acronym for a change in velocity (ΔV) plus an Earth gravity assist (EGA), is the same technique used so successfully to guide the Voyager spacecraft on their tour of the outer planets with low propellant requirements. This mission would maintain all or nearly all of the ten planned encounters of the Galilean satellites. The tour design, however, depends greatly on many factors, such as launch date, arrival date, and launch energy.

Another launch option occurs in January 1991 with a 2-year ΔVEGA trajectory. Galileo could then be launched either from the shuttle or on a Complementary Expendable Launch Vehicle (CELV) Titan 34D7, a larger version of the vehicle which launched the Viking and Voyager spacecraft. The CELV is still in development by the Air Force and will not be available for Galileo until at least the January 1991 launch opportunity.



Options under study to recover the full 10-encounter tour include using larger tanks on the Retro Propulsion Module. Approximately one additional orbit can be achieved with each 5% increase in tank size. The possibilities of Earth-Moon science and an asteroid encounter are also being explored.

In the last few months, we have continued with test and integration activities at Kennedy Space Center, Florida. End-to-end data flow tests and integration tests were successfully conducted. Both the development test model and the flight spacecraft have been mated to the Centaur upper stage in the Vertical Processing Facility. The RTGs have also been mated to the spacecraft. We are now preparing to ship the Galileo orbiter and probe to JPL sometime in August.

In the meantime, planning for future launch opportunities continues. We are taking advantage of the delay to replace the attitude and articulation control, command and data, and power and pyro subsystems spares that were transferred to Magellan.

The spacecraft is hoisted beside (left) and then lowered onto (below) a Centaur rocket (held upright within the scaffolding). These tests at Kennedy Space Center "attached" the spacecraft to the launch vehicle, and then separated the two for storage.

Safety analysis also continues, with safety assessments and the development of shields for the orbiter's RTGs, should they be required.

The design of the new flight path to Jupiter will be a challenging task in light of uncertainty about shuttle lift capability, modifications to the IUS injection module, and potential shielding of the power generators. In addition, although the final design of the satellite tour at Jupiter will not be done until after launch, a major tour design effort is necessary now to help in the selection of the Jupiter arrival date. This arrival date is scheduled to be selected in the fall of 1986.

The Galileo mission to Jupiter is vitally important to our understanding of the solar system and the world in which we live, and with your support, we will assure its success.

— J.R. Casani

Plasma Wave Investigation

From grade school on, we have been taught that space is a black, empty void, interrupted by occasional planetary systems or stars. This is an unfortunate misconception. True, space is a vacuum. But it is not totally empty.

Low-density, ionized gases called "plasmas" emanate from the Sun, the planets themselves, and some of the satellites. Composed entirely of atoms that are broken apart into electrons and charged positive ions, a plasma is a good electrical conductor with properties that are strongly affected by electric and magnetic fields. The solar wind is a plasma of charged particles travelling outward from the Sun at supersonic speeds, sometimes accelerated by solar flares.

Individual ions and electrons in a plasma interact with the rest of the plasma by both emission and absorption of waves. These low-frequency oscillations originate in instabilities in the interplanetary plasma. Plasma waves are of two types: electrostatic oscillations similar to sound waves, and electromagnetic waves.

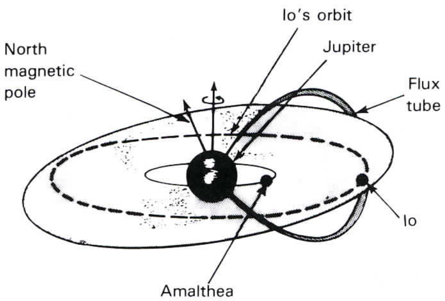
Localized interactions between waves and particles strongly control the dynamics of the entire plasma medium. Plasma waves generally cannot be studied far from their sources, so we must rely on our spacecraft observations to study plasma waves near the planets and in interplanetary space.

Galileo will carry instrumentation designed to study plasma waves. An electric dipole antenna will study the electric fields of plasmas, while two search coil magnetic antennas will study the magnetic fields. The electric dipole antenna consists of two 10-meter graphite epoxy antennas mounted at the tip of the 10-meter-long magnetometer boom. The search coil magnetic antennas are mounted on the high-gain antenna feed. Nearly simultaneous measurements of the electric and magnetic field spectrum will allow electrostatic waves to be distinguished from electromagnetic waves.

As with all of the Galileo fields and particles instruments, the plasma wave subsystem is mounted on the spinning section of the spacecraft. Scientists will thus be able to use radio direction-finding techniques to determine the source of certain types of plasma waves.

By virtue of its extended tour of Jupiter's system, Galileo will afford long-term observations not obtainable with previous flyby missions.

The Voyager missions detected several types of plasma waves and radio emissions near Jupiter. Galileo will study the mechanisms by which these waves are produced. For example, electrostatic electron cyclotron waves occur near the equatorial plane in and around the plasma torus that surrounds Io. Galileo will allow three-dimensional measurements of this area to aid in understanding why these types of waves occur in the torus. At the inner edge of Io's torus, auroral hiss emissions were detected, similar to emissions associated with low-energy electron beams and field-aligned currents in Earth's auroral regions. Further study of these emissions at Jupiter should unveil much about energy transfer between the Io torus and Jupiter's ionosphere, and about polar auroras on Jupiter that occur along Jovian magnetic field lines that pass through Io.



The plasma torus surrounding Jupiter

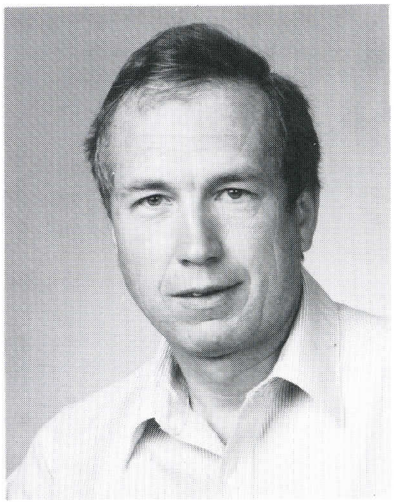
Jupiter is the most intense radio source in the sky. Voyager detected several types of radio emissions from the inner region of Jupiter's magnetosphere. These include decametric and kilometric radiation (the names relate to the length of the radio waves), and Galileo will search for the source of these radio waves.

In addition to studying locally generated plasma waves, Galileo's plasma wave subsystem will be used as a remote sensing tool to monitor changes in the inner magnetosphere during the long periods that the spacecraft is near apojove (the highest point above Jupiter in each orbit). Large changes occur in Jupiter's radio emissions on time scales ranging from a few hours to several months, but the reasons for this are not presently known.

During the orbital tour, the spacecraft will pass many times through the turbulent boundary between the magnetosheath and the quieter inner regions of the magnetotail.

The final orbit of Galileo's Jovian tour will take the spacecraft down the planet's magnetotail—the windsock-shaped region of the Jovian magnetosphere that trails away from the Sun as the solar wind blows past the planet. Scientists expect to gain important information on the structure and dynamic processes in the magnetotail. At Earth, important plasma energization processes occur in the terrestrial magnetotail.

All of Jupiter's four largest satellites—Io, Europa, Ganymede, and Callisto—lie well within the planet's magnetosphere. Consequently, there are interesting interactions between these large orbiting bodies and the rapidly moving plasma which is being



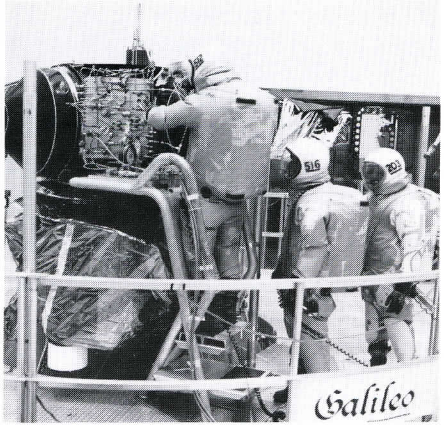
Don Gurnett

Part of the Galileo propulsion team poses with the spacecraft in a clean room at Kennedy Space Center. Back row from left, Lloyd Swanson, Connie Rodriquez, Eugene Poyorena, Glenn Bummer, Gunther Kienlein, and Herbert Stangl. Kneeling, from left, Jim Lumsden and Mary Reaves. Not shown are Hank Delgado, Jay Garcia, Homer Cross, Warren Dunn, Bill Reilly, Bert Turney, Dave Quarles, Dick Bonner, Ron Brubaker, and Doug Horman.

swept around in space with Jupiter's rotation. Wakes are formed as the plasma is swept past slower-moving satellites. Many things influence the interactions, including the size and magnetic moment of the satellite, the flow velocity and magnetic field strength of the co-rotating plasma, the surface properties of the satellite, and the satellite atmospheres, if such exist. We know that Io, for example, has a very strong interaction, accounting for a power input of 10^{12} watts into the Jovian magnetosphere. At Saturn, the atmosphere of the satellite Titan may actually be being swept away by the planet's rapidly rotating magnetosphere. Studies of plasma physics at Jupiter promise to be intriguing.

Principal investigator for the plasma wave observations is Don Gurnett of the University of Iowa, Iowa City. There are four co-investigators. □

— A. Sohus



Propulsion engineers wearing pressurized protective suits load propellant into the tanks of the Galileo orbiter's retropropulsion module in a clean room at Kennedy Space Center.

Meet The Team

When he's not restoring his 1962 Corvair convertible, putting the finishing touches on his amphibious, all terrain automobile, or keeping up with his 8-year-old son, Maynard Hine catches all the loose ends of the Galileo project. "If it doesn't fit anywhere else, I get to do it," he says.

His job entails supervision, communications, documentation, scheduling, personnel, facilities, and reviews. And, while the spacecraft is at the Kennedy Space Center, he is covering for the "head secretary" while she is at the Cape. Perhaps one of his favorite aspects of his job involves the occasional designing of special facilities, such as the rear projection system used in the Project Conference Room.

This diversity of talents comes from a varied background. Maynard has been designing and constructing buildings and special facilities since the age of 13, when he began working with his father. He later studied architecture at the University of Oregon. He worked for Hopkins Engineering Co., an electronics firm, for 4 years, and then Hopkins gave him a scholarship to UCLA to study physics while continuing to work for the firm as an engineer.

With JPL since 1955, originally as an architect for two years, his only break from the Lab was when he joined the Army Corps of Engineers. Upon returning to the Laboratory, he worked as an engineer on the Sergeant Missile System, the Space Flight Operations Facility, Ranger, Mariner Venus flyby, Surveyor, Mission Operations, and the Flight Science Experiments Project Office, before teaming with John Casani, as his staff assistant on Voyager. When Casani moved to Galileo, Maynard joined the project as well.

Although his official title is Senior Staff Assistant, Maynard seems to have trouble shaking the image of his one-time project title of "Fireman," because it seems I only get a job once its caught fire."

When not extinguishing fires, Maynard enjoys photography (once a part-time job), fishing, camping, hunting, and traveling. He is a Rangemaster for the JPL Gun Club and an NRA (National Rifle Association) Certified Instructor in marksmanship and gun safety. The gull-winged, amphibious vehicle he has been working on for a number of years is a marvel of safety and reliability. The fuel system alone has 17 backup systems in case of breakdown.

Maynard has promised this vehicle to his 8-year-old son, Matthew. He and his wife, Bonnie, are constantly surprised and delighted with their son. Smart and outgoing, Matthew once prompted a stranger to say, "I don't know what office you're running for, but I'll vote for you." Like father, like son.

Maynard Hine

Software

"Software has become a larger part of space missions, and Galileo is more 'software intensive' than any other spacecraft that JPL has flown," notes Patricia Molko, Galileo's Software System Manager.

Development of Galileo's on-board software was one of the Project's many challenges. The Orbiter contains 10 engineering subsystems and 19 microprocessors, with a total of about 320,000 (8-bit) bytes of random-access memory (RAM) and 41,000 bytes of read-only memory (ROM). In contrast, each Voyager spacecraft contains 70,000 bytes of memory.

The primary responsibility for command, control, and data handling rests with the Command and Data Subsystem (CDS), which consists of six RCA 1802 8-bit microprocessors and a high-speed data bus. The CDS distributed system consists of approximately 15,000 lines of structured assembly language and represents a major advance in the state of the art since Voyager.

The second large software-controlled subsystem on Galileo is the Attitude and Articulation Control Subsystem (AACS). Voyager's AACS could not be used directly for Galileo because of the Galileo spacecraft's new, complex dual-spin configuration. The AACS software is responsible for determining attitude and for controlling Galileo's spin rate, propulsion subsystem, and scan platform (where the remote-sensing science instruments are located). These and other functions are implemented by complex algorithms in the high-order computer language HAL/S. The subsystem consists of approximately 7,500 lines of code that operate on two high-speed 2900 ATAC-16 microprocessors, each with 32,000 words of memory.

Both the AACS and CDS contain fault-protection algorithms to respond to on-board faults, which, if left unattended, could result in major mission losses. Each subsystem is also reprogrammable, which allows scientists and engineers to compensate for any spacecraft idiosyncracies or limitations discovered while in flight. Galileo's probe and science instruments (with the exception of the Plasma Wave Subsystem) also contain microprocessors and software that provide overall instrument control, primarily via ROM.

The ground-based software supporting the mission operates on a wide variety of both large, institutional computers and mini- and microcomputers. More than 2.5 million lines of code will help the Galileo Flight Team in preparing commands to send to the spacecraft and in analyzing the data sent back to Earth. Although a large percentage of the software was inherited from previous flight projects, a significant amount of new software was developed, primarily in the Mission Sequence System and Orbiter Engineering System.

The management for developing these complex software systems was another significant challenge. In 1978, when the system requirements were first being defined, JPL had no institutional software standards. A Software Thinking Group, composed of senior JPL engineers and programmers, was formed to define the Galileo software development and management methodology. NASA Management Instruction 2410.6 provided software management requirements upon which the Galileo Software Management Plan was written. The system development life cycle is divided into phases. Each phase consists of several milestones. Completing each milestone requires specific items to be produced, reviewed, and placed under configuration control.

Several new concepts were part of the methodology and proved to be useful techniques in managing software. More detailed planning and monitoring of software schedules were required and found to be a key item critical to success. Another new philosophy was phasing the delivery of capabilities in the software — building and testing the software in increments. Scientists and users were encouraged to participate in the software review process to ensure that the software would meet their needs. The recently approved *JPL Institutional Software Standards* (Document 500-512) incorporates these, as well as other proven concepts for software development and management.

In praise of the many people involved in the software task, Molko said, "The dedication, hard work, patience and understanding, team effort, and sense of humor are all qualities that helped our software team achieve the goal of delivering a high-quality set of software which will make possible the last great interplanetary mission of this century."

Q & A

Q. Why does the Galileo spacecraft use nuclear generators for power, rather than solar cells?

A. The Galileo spacecraft will be functioning at a distance of over 500 million miles from the Sun. At that distance, the Sun's energy and light are only 1/26 as strong as here on Earth, due to the inverse square law of energy propagation. The Sun's light is too feeble at Jupiter's location to create enough power via solar cells to be useful. With spacecraft that explore the inner planets, the problem does not exist since the Sun's light is strong enough.

Q. What is the difference between a "launch period" and a "launch window"?

A. A launch period is a set of contiguous days on which it is possible to launch onto a trajectory that will encounter the target planet. A launch window is that interval on a day in the launch period when launch may occur. Generally, launch periods are one to two weeks in duration, and launch windows range from a few minutes to a couple of hours. Both are determined by trajectory requirements and launch vehicle performance.

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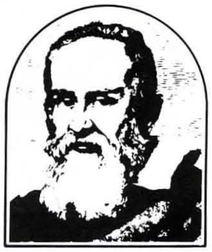
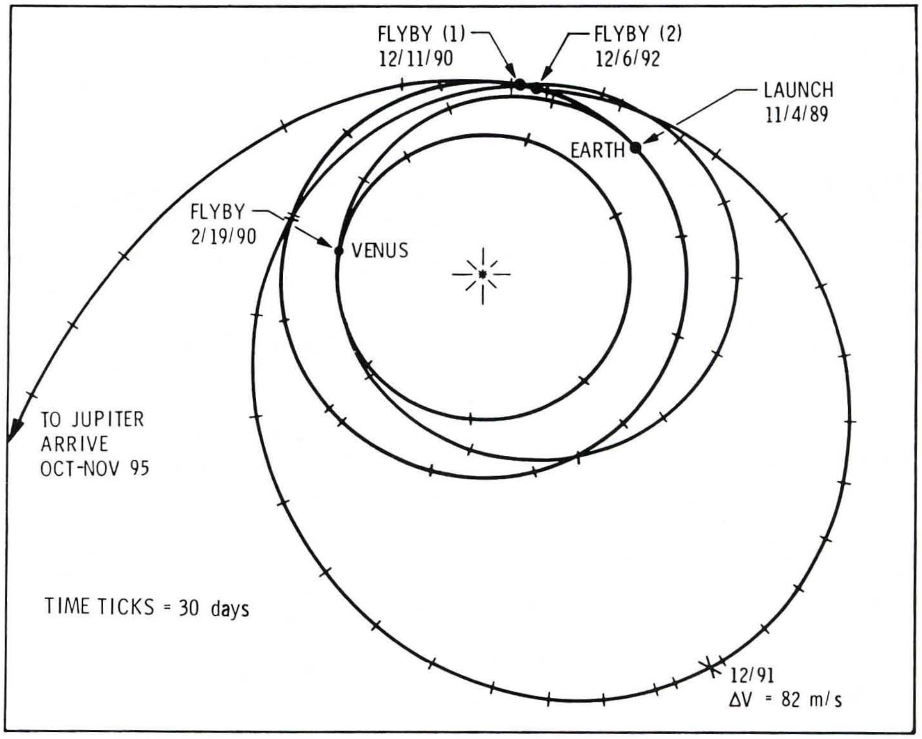


The Galileo Messenger

Issue 17 December 1986

From the Project Manager

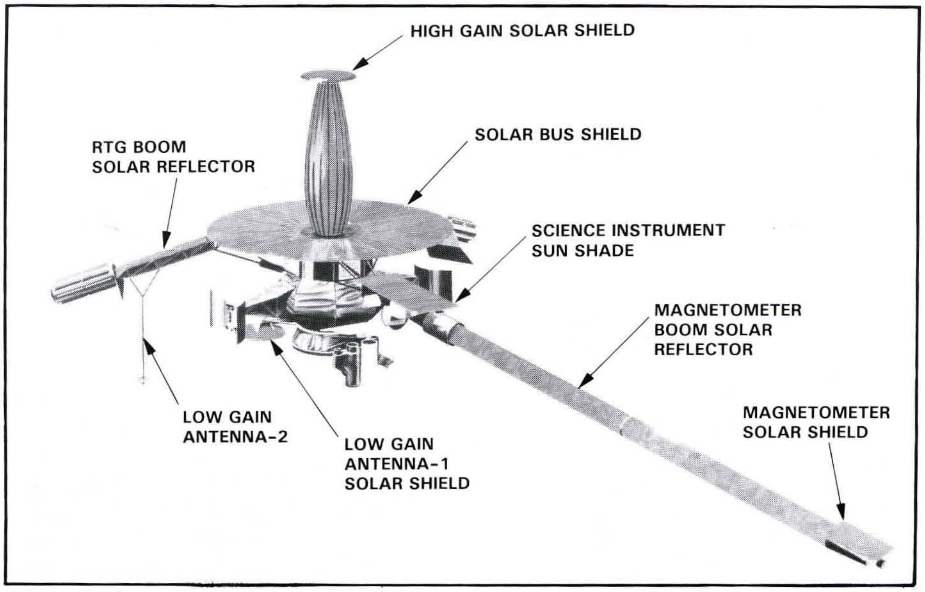


The VEEGA mission trajectory.

While awaiting NASA's final decision on the launch date for the Galileo mission, many important events have occurred. We all regret the departure of Al Wolfe, who is now Chief Engineer of Flight Projects for the Laboratory. Al had been with Galileo since 1977 as the Deputy Project Manager. Al's professionalism, thoroughness, and dedication will be missed, but we wish him well in his new position.

Over the past few months there have been mission changes, as well as management changes. As you may recall, most early plans for Galileo called for direct flights to Jupiter. The Centaur upper stage provided sufficient energy to place the spacecraft on a direct trajectory.

After the Challenger tragedy on January 28, 1986, NASA placed severe new constraints on shuttle operations and cancelled the shuttle/Centaur program. Without the Centaur, a direct flight to Jupiter was impossible. Investigation of a new launch-vehicle configuration began in concert with new trajectory options to see which would allow Galileo to arrive at Jupiter and perform a mission with the greatest possible science return. Those studies included ΔVEGA trajectories, various shuttle/upper-stage combinations, and expendable launch vehicles.



The VEEGA mission antenna and thermal control modifications to the spacecraft are highlighted.

Dr. Roger Diehl began to investigate a new series of low-energy launch options. He soon realized the way to get to Jupiter using a low-energy launch was to go first to Venus — the Venus-Earth-Earth Gravity Assist (VEEGA) trajectory concept, nicknamed the "Solar Cruiser."

This new trajectory requires a series of modifications to the spacecraft for thermal protection, telecommunications requirements, and the six-year-long cruise.

Galileo was designed to operate between 1 AU and 5 AU from the Sun [1 astronomical unit (AU) = 150,000,000 kilometers or

— see page 4

Radio Science

There are three separate radio science experiments planned for the Galileo mission: radio propagation, celestial mechanics, and gravitational wave search. Although all have certain hardware in common, they utilize different radio signals at various times.

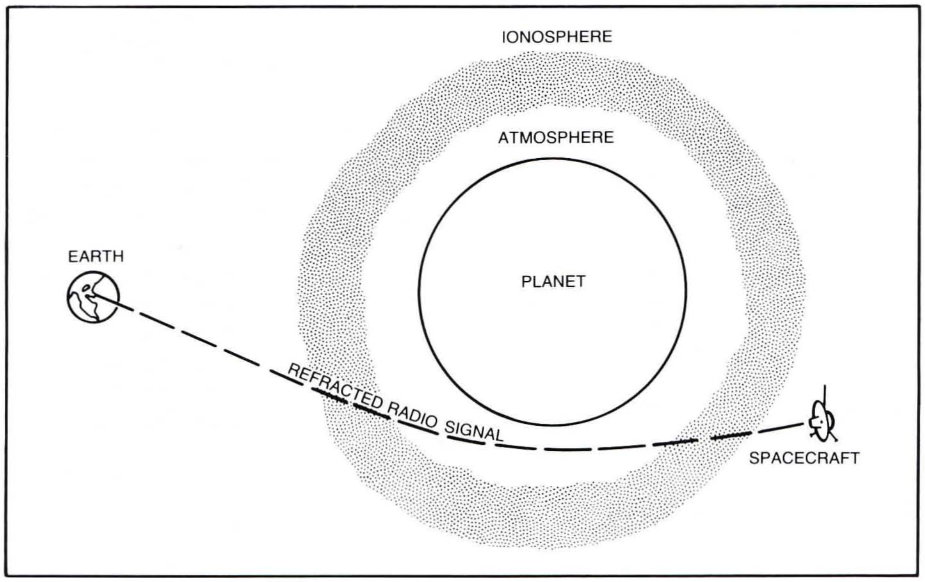
Measuring Radio Waves

The radio propagation team will investigate Jovian atmospheric temperatures, pressures, and structures, and will search for ionospheres of the satellites. In addition, the team will study the solar wind and Jupiter's inner magnetosphere.

The radio propagation experiments measure the minute changes in frequency, power, time delay, and polarization of the spacecraft's radio signal, left over after the speed and position of the Orbiter are removed. The experiments can be conducted when anything is between the Earth and the spacecraft: a planet, a satellite, the Sun, or the solar wind. These are usually times when the signal is too noisy for navigation or celestial mechanics experiments (although there is occasionally some overlap). As Jay Breidenthal, the science coordinator for radio propagation, says, "one man's noise is another man's data."

For example, when Jupiter's atmosphere is between Galileo and the Earth, a signal emitted from the spacecraft will travel through the Jovian atmosphere in order to get to Earth-based antennas. As a consequence, the radio signal received is slightly different than the signal originally sent. "This is due, in part, to bending of the radio waves, as well as the effects of layering, turbulence, and bubbles of hot and cold gas in the atmosphere upon the radio signal," explains Breidenthal.

A related atmospheric experiment will be conducted during the descent of the Probe. Using the radio signal between the Probe and the Orbiter, the team hopes to observe changes in the wind speed with altitude and to gain some understanding of whether heat is moving downward or upward through the atmosphere.



When Galileo's radio transmitter beams a signal through Jupiter's atmosphere, the changes in the signal allow scientists to estimate the atmospheric density, temperature, and pressure.

Another radio propagation experiment will study the solar corona. When Jupiter, and consequently the spacecraft, are on the side of the Sun opposite from Earth, a signal sent from the spacecraft must travel through the solar corona before reaching the Deep Space Network's (DSN's) antennas. Therefore, scientists will study the Sun with the same techniques they will use at Jupiter.

One interesting but puzzling phenomenon scientists hope to better understand is the acceleration of the solar wind. At the surface of the Sun, the solar wind is traveling very slowly. Yet, by the time it reaches the orbit of Mercury, it has accelerated enough to escape the Sun's gravitational pull.

The signals from Galileo will be filled with "noise" from a variety of radio sources and will be incredibly weak (about a billion times fainter than the sound of a transistor radio in New York as heard from Los Angeles), and the effects are very minute (about the same as measuring the distance between New York and Los Angeles to an accuracy of a human hair). Needless to say, these measurements are difficult. So much signal power is lost cutting through Jupiter's atmosphere that the ordinary receivers used for telemetry will no longer function. However, the team plans to continue recording even after the signal appears to stop. With subsequent computer enhancement, they will be able to extract another hour's worth of data — about a 30% increase in data acquisition for each occultation.

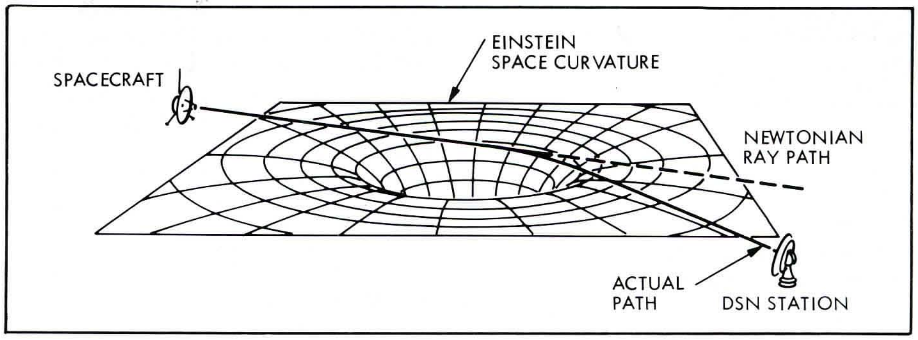
For Galileo radio science, it proved advantageous to put about 80% of the measuring equipment at the DSN stations, quite unlike the other experiments which have nearly all of their equipment on the spacecraft itself. Emphasizes team leader H. Taylor Howard, "Our ground-based equipment is both a curse and a blessing. It is complex and requires careful adjustment; but if there is a failure or we find something surprising, we don't have to pack up and go home — repairs and changes can always be made."

The U.S. team has joined forces with the Deutsche Forschungs und Versuchsanstalt für Luft und Raumfahrt (German Institute for Aerospace) for studies of the Sun during Galileo's cruise to Jupiter.

Partially in preparation for the Galileo radio propagation studies, the DSN is building several new

antennas and receiving systems. The new equipment will be able to continuously detect and calibrate the slowly rotating, linearly polarized signal from Galileo. Existing antennas either were too inefficient or could follow only a few turns before losing the signal, and existing receivers were not accurate enough.

Involved in the radio propagation task are five scientists dedicated to radio propagation, as well as several other team members who work on all three radio science experiments. The team leader for the experiments is Professor H. Taylor Howard from Stanford University.



The curvature of space actually bends the radio signal between Galileo and the Earth.

Performing Celestial Mechanics

The Celestial Mechanics (CM) and Relativity experiment on the Galileo spacecraft will more exactly determine the orbits and will reveal information about the interior compositions of Jupiter and its satellites (whether there are definite boundaries of rock and ice or whether they are homogeneous throughout).

The gravity fields of the planet and satellites will be measured. Much as our moon affects ocean tides on the Earth, so any large body influences another near it. Jovian gravitational fields will affect the flight of the spacecraft, and Earth-based observers can measure that effect.


H. Taylor Howard

To do this, a two-way radio link will be established between Galileo and the ground stations on Earth. A signal sent from Earth to the spacecraft, in either the S-band or X-band, will then be returned by the spacecraft to Earth. Because of the tugging of gravitational fields upon the spacecraft, the radio signal will be altered slightly. The difference between the signal received and the one sent will give valuable data to the science team.

Often the radio signal will be scintillated. Such outbursts denote interference from a variety of sources, including interplanetary media and the particle environment around Jupiter.

The CM team will utilize an S-band uplink, a transponder, and a 5-m parabolic dish antenna to send simultaneous, clear downlink signals at two different frequencies. The CM is a part of the radio science system onboard Galileo. The team leader for the CM experiment is Dr. John Anderson.

Searching for Gravitational Waves

A very different aspect of the celestial mechanics experiment involves a search for gravitational waves. Gravitational waves are extremely faint perturbations in the interstellar medium caused by momentous occurrences.

The idea behind the Gravitational Wave Search (GWS) is that there is constant gravitational radiation from the cosmic background. Very rarely, when stellar or galactic catastrophes happen, this background is overwhelmed and a "pop" may be heard at very low frequencies (with periods of about 20 minutes). The GWS will hear three "pops" at the Earth-based detectors — one at the Earth, its echo, and one from the spacecraft.

For example, if two black holes were to collide, the collision would set up a gravitational rippling in the interstellar medium. That ripple would eventually reach the radio signal stretched between Galileo and the Earth. Scientists would detect three "pops" as the ripple passed through and interfered with the signal. The Ulysses spacecraft, also in that region of space, could possibly then confirm the detection.

John Anderson explains, "We will only see catastrophic events, perhaps the collapse of an object with 10,000,000 times the mass of the Sun. While we hope to actually detect gravitational waves, the absence of any waves will still give us valuable information."

The problem for searchers today involves the limits of the length of Earth-based detectors. Ideally, a detector would be several billion miles long. Galileo presents a unique opportunity, because the detector will be the radio signal stretched between the spacecraft and the Earth: a detector about 2 billion miles long. If gravitational waves exist, as scientists surmise, then there is about a 40% chance of detecting these waves on Galileo's cruise to Jupiter. Different events will have different radio signatures . . . a black hole will "sound" distinctly different from a binary pulsar.

When such waves are detected, the GWS team, led by Dr. Frank Estabrook, can help ground-based observers scan the skies for visual confirmation and identification of the source of the waves.

(continued from page 1)

93,000,000 miles]. The trip to Venus will carry Galileo between 0.68 and 0.71 AU from the Sun. Such passages pose severe thermal problems. These will be solved with the use of thermal shades and shields and different external blanket material.

In its present configuration Galileo is equipped with two antennas. However, during the Venus-Earth-Earth phase, both antennas will point away from the Earth for up to several hundred days for thermal control reasons. This creates a telecommunications problem which will be solved by adding a small low- or medium-gain antenna to the radioisotope thermoelectric generator (RTG) boom for use during this period.

Other alterations include sequencing changes for the new mission phases and integrating the new launch vehicle. Changes to the power management and related fault protection will also be required, since the radioactive fuel decay associated with the 1996 arrival date will result in reduced power from the RTGs.

The VEEGA trajectory for the Galileo mission has a 400-kg (880-lb) launch-vehicle weight margin and about an 80-kg (176-lb) spacecraft-propellant margin (the amount of propellant remaining after the nominal primary mission is completed). These margins are much larger than the margins offered by nearly all previous mission designs. Furthermore, the fully loaded Galileo spacecraft and two-stage IUS fall well within the cargo weight restrictions imposed on future shuttle flights.

The May 1986 launch plan included a flyby of the asteroid Amphitrite. The Amphitrite opportunity is lost, but since Galileo will make two passes through the asteroid belt the prospects for finding another asteroid target are good.

Our crew at the Kennedy Space Center has finished the electrical testing on the Orbiter. Most of the crew returned home for the Thanksgiving holiday, and will remain here until just before launch in 1989. The spacecraft, originally planned for return to JPL last August, is being kept at the Cape for further software testing and troubleshooting. We are decontaminating the retropropulsion module oxidizer tanks which had been filled for the May 1986 launch. The spacecraft will then be returned to JPL in February 1987 for VEEGA modifications. Following this work, Galileo will undergo a new series of system-level environmental tests in 1988.

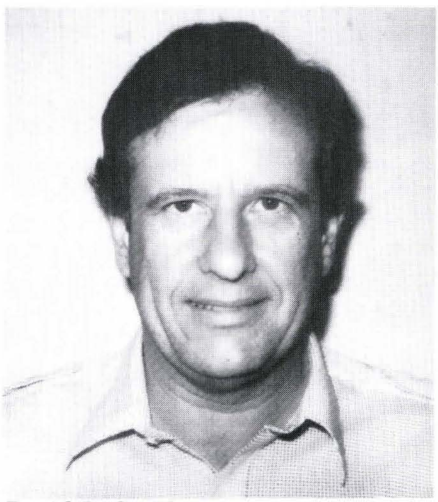
The Probe was sent to JPL from Hughes last month. The science instruments have been removed and are being upgraded. Re-integration of the Probe and instruments is scheduled for early 1988.

— J.R. Casani

Meet the Team

Many people have been with the Galileo Project for a number of years; however, few can say they started earlier than David Smith. In 1973, as Trajectory Mission Design Group Supervisor, Dave Smith co-authored a paper entitled "Jupiter Orbiter Probe Tour Mission." This was the first complete description of what was to become the Galileo Mission.

As manager of JPL's Spacecraft Data Systems Section, Dave is responsible for the Galileo Orbiter's Command and Data Subsystem (CDS). Recently, John Casani, Galileo Project Manager, asked Dave to prepare an additional CDS (with over 12,000 components) for Galileo, a job which will take Dave's section over 12 months to complete. Galileo's spare was slightly modified and given to Magellan without the despun section.



David B. Smith

Dave began his scientific career at the University of West Virginia in 1958, majoring in aerospace engineering. He received his master's degree from USC in 1965, and then went to TRW. He has been with JPL since 1971 in a variety of capacities including the Low-Thrust Navigation Team leader, Magellan and Halley Science and Mission Design Manager, and Mission Design Section (312) Manager. His diversity of jobs reflects his personal strength, "I'm well-rounded . . . not too specialized, but competent at many things."

His first job at the Lab had nothing to do with deep space missions. JPL had a contract with the Department of Transportation to develop a personalized rapid transit system (a robotic system like the automated tram that used to be at JPL). The system would become a part of "Morgantown" at Dave's alma mater. "It was very exciting, returning to West Virginia to meet and work with the people back there," he remembers.

A man of many interests (a member of the JPL Gun Club, a chess player, and a bridge player), he is perhaps most passionate about sports. In high school, he was an all-state player in baseball, basketball, and football. In fact, he was once tempted to pursue a career coaching college football instead of engineering. And, although he did play semi-professional football with the California Razorbacks (a member of the Western Football League), the Galileo Project is pleased he chose to remain in science.

Dave and Nancy, his wife of 27 years, have three children. When asked about future plans, Dave quipped, "My only plan is to deliver a CDS to John Casani."

Editor . . . . Jeanne Collins

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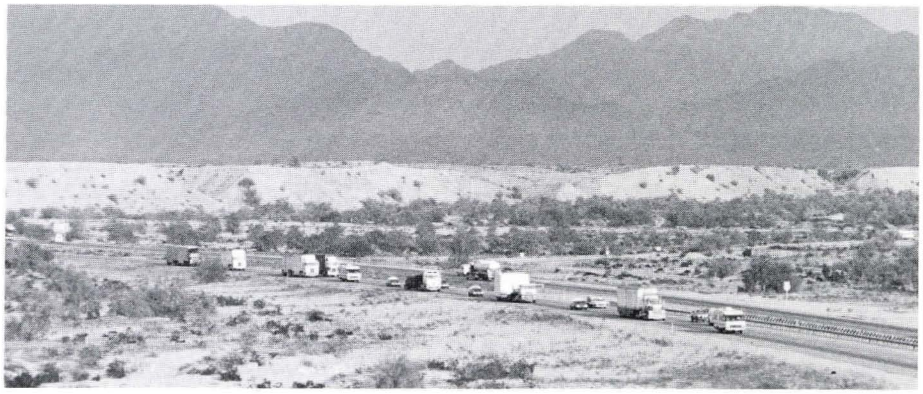
The Galileo Messenger

Issue 18 **April 1987**

From the Project Manager

NASA has announced that Galileo will be launched in October or November 1989 from the Shuttle. Ulysses, therefore, will be launched in October 1990. The decision, announced jointly by NASA Administrator James Fletcher and European Space Agency Director General Reimar Luest, was "principally based on a desire to optimize the data return from these two important scientific missions. To delay Galileo until 1991 would have resulted in an additional two-year delay in beginning to receive prime data from the Jovian environment."

We have been working with a fall 1989 launch as a baseline, and are very happy to have a NASA commitment to this date. However, this means we will be extremely busy over the next two-and-a-half years. The spacecraft sent to the Kennedy Space Center in December 1985 was prepared to be launched from the Shuttle aboard a Centaur, to study the asteroid Amphitrite, and to conduct a two-year mission at Jupiter beginning in 1989. In April 1989, we will send a very different spacecraft to the Cape for launch. Galileo (now back at JPL) is being reconfigured not only for changes in the mission, but also for changes in the launch vehicle, cruise science opportunities, and mission duration.



The convoy of trucks and motor homes bringing Galileo back to JPL crosses the California desert.

The VEEGA (Venus-Earth-Earth Gravity Assist) mission, because it sends Galileo much closer to the Sun, requires substantial thermal modification and testing to the spacecraft. Sun shades and new blanketing are being developed and a new battery of thermal tests is under consideration for this mission. Programmers are reworking the software to accommodate the complex VEEGA mission requirements. Another antenna is being built for addition to one of the RTG booms to enable communication with Earth while the existing antennas are pointed away for thermal control reasons.

The hardware which connects the spacecraft to its launch vehicle is also being redesigned and built. The Inertial Upper Stage (IUS) two-stage rocket will be used to boost Galileo out of low-Earth orbit.

Potential Asteroid Opportunities

Asteroid	Diameter, kilometers (miles)	Encounter Date	Relative Velocity, kilometers/second (miles/second)
Ausonia	92 (57.0)	April 9, 1992	8.2 (5.1)
Gaspra	6 (3.7)	October 29, 1991	8.0 (5.0)
Ida	13 (16.1)	August 27, 1993	12.5 (7.8)

With the VEEGA mission Galileo will take six years to reach Jupiter, and we will have a variety of opportunities for scientific study during cruise. Discussions are underway for possible science at Venus, at both Earth encounters, and at both passes through the asteroid belt. Three potential asteroid opportunities are being considered: Ausonia, Gaspra, and Ida (see the Table). The size and velocity (relative to the spacecraft) of the asteroid are both important considerations in choosing a target.

Finally, shelf-life and aging tests are an ongoing concern to the Project. The previous mission's end-date was October 1990. With launch now in 1989, Galileo will be collecting data through 1998. Certain parts will need to be replaced or augmented to work effectively through that time.

We all have a lot of challenges ahead of us to complete the rework of the spacecraft and mission for the October/November 1989 launch date. With this firm commitment from NASA regarding Galileo's launch date and the Project's undeniable importance to the space program, we will be delivering a spacecraft which will return data Galileo Galilei never dreamed possible.

— J. R. Casani

Net Flux Radiometer — Studying the Atmosphere

Pioneer and Voyager spacecraft passing by Jupiter measured radiation leaving Jupiter's cloud tops, but we can only theorize about the nature of radiation within the atmosphere. In contrast, the net flux radiometer (NFR) in the Galileo Probe will directly sample the local radiation flows within and below the Jovian cloud layers.

Probe Descent

As the Probe descends through various atmospheric layers, there will be observable changes in the net radiation flux. These changes will reveal the driving forces for atmospheric motions: If more radiation enters a layer than leaves it, that layer is radiatively heated, and other layers are radiatively cooled. The temperature differences that tend to arise from the radiative heating and cooling produce bouyancy differences and, ultimately, atmospheric motions. Identification of such layers, and the magnitude of the heat deposited or lost, will comprise the fundamental measurements of the NFR.

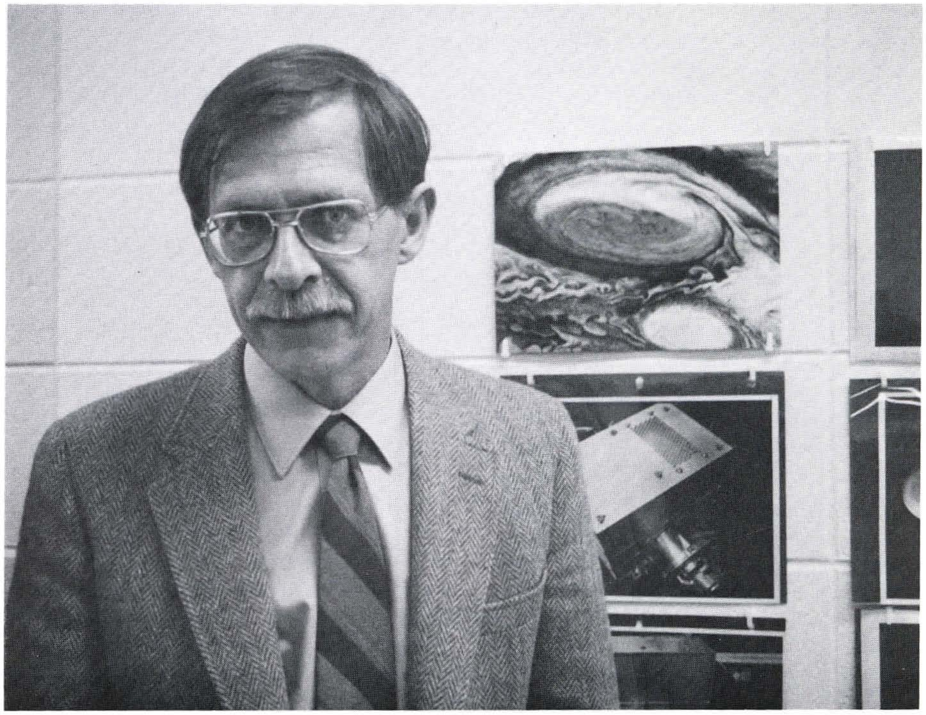
Composition Analysis

A second major objective of the NFR is to help identify components of the Jovian atmosphere. The vertical profile of net radiation flux will show dips in regions where the atmosphere absorbs radiation relatively strongly. Furthermore, the NFR will measure dips (which are increases in opacity) with several spectral bands. The magnitude of such dips can be correlated with the temperature and pressure measurements of the Probe's atmospheric structure experiment and with the particle backscatter measurements of the nephelometer. Together, these three data types will provide significant constraints on the nature of the atmospheric material causing each region of greater absorption.

The NFR uses a rotating optical head in which detectors view a 40-degree cone of atmosphere through a diamond window. The viewing cone is centered at a 45-degree angle as the most representative angle for estimating the integrated energy from an entire hemisphere. A horizontal rotation axis allows both upward and downward hemispheres to be viewed by the same optics and detectors. During the descent into a continuously hotter and denser atmosphere, the NFR will rapidly alternate between looking upward and downward. Measuring the difference in radiation intensity between these two views will determine the magnitude and direction of the net flow (net flux) of radiative energy.

Behind its single diamond window, the NFR has six lithium, tantalate, pyroelectric detectors viewing through filters extending from the visible to infrared wavelengths. One filter is used to measure the deposition of solar energy, while a second is used to measure the integrated infrared energy flux. Three additional spectral regions were chosen to help identify various atmospheric species.

It is well established that molecular hydrogen is the major source of gaseous opacity in Jupiter's atmosphere. However, hydrogen has "windows" or "holes" in its spectrum through which the atmosphere would lose tremendous amounts of radiation to space were it not for the minor constituents of methane, ammonia, and water vapor that fill the holes in the hydrogen spectrum. By measuring the net flux as a function of altitude in the hydrogen windows, it is possible to estimate the abundances of the trace gases. This provides a crude backup to some of the mass spectrometer measurements. More directly valuable are the measurements of opacity contributions by particulates within the atmosphere. The location of cloud layers by their effects on infrared and visible opacity also provides a partial check on the cloud particle observations of the nephelometer.



Principal Investigator Dr. Larry Sromovsky will utilize the Net Flux Radiometer's data to examine Jupiter's atmosphere.

Optical Comparison

Because the net flux during descent becomes very small compared to the total energy flux, there are severe requirements on optical symmetry between upward and downward views (the classic

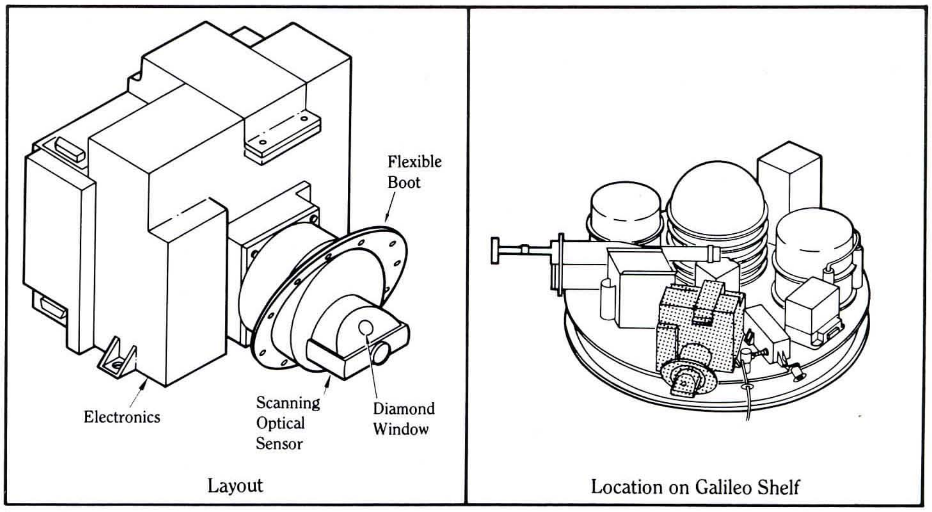
problem of subtracting two large numbers applies here). To ensure that detector illumination and window characteristics don't change between upward and downward views, the entire optical system is rotated as a unit to obtain the two views.

In addition to the net flux measurement, the NFR also measures, every other minute, the upward atmospheric flux and the flux from an onboard blackbody. The onboard radiometric calibration system is used to monitor system performance during descent. In the net flux mode, the NFR looks up and down twice per second. In the calibration mode, the NFR flips between two internal radiation sources: a blackbody at ambient temperature and a hot blackbody at a controlled temperature of 410 kelvins. In the up-flux mode, the NFR flips between viewing downward and viewing the heated target.

In each mode, the net flux signal is integrated for 5.5 seconds and sampled every 6 seconds. In each two-minute NFR cycle, there are 20 six-second instrument cycles, of which 17 are devoted to net flux measurements, and one each to up-flux measurement, blackbody measurement, and analog zero check. This same data format is used throughout the descent, providing a vertical resolution of about 1.2 kilometers (0.74 miles) while the Probe is descending rapidly, and a gradually finer resolution as the descent rate slows. At a level of pressure 10 times that at Earth's sea level, the vertical resolution will be about 0.2 kilometers (0.12 miles).

The NFR has a mass of 3 kilograms (6.6 pounds) and will use an average of 10 watts during descent. It was built by Martin-Marietta Denver Aerospace. The principal investigator is L. Sromovsky at the University of Wisconsin (Madison). Other team members are H. Revercomb (also at Madison), J. Pollack at Ames, P. Silvaggio and J. Hayden at Martin-Marietta in Denver, and M. Tomasko at the University of Arizona (Tucson).

— Roger V. Carlson



As the Probe descends through the atmosphere, the Net Flux Radiometer (NFR) collects data to determine cloud layer location and atmospheric-constituent mixing at various altitudes. The NFR is located on the equipment shelf periphery to allow the optical head to extend through the Probe's aerofairing.

Aging: Its Effect on the Spacecraft

The aging of the Galileo spacecraft's parts is a pressing concern to the Project. Just as any piece of equipment has a certain expected lifetime of operation, so too batteries, paints, and rubber parts will wear out or age after a short while. With Galileo's arrival at Jupiter delayed another six years, some of these parts will be at or beyond their expected lifetimes.

There are a variety of areas being studied for possible aging effects. Some of these include degrading flexibility of cable coverings, losing adhesion on conductive tape, corroding or rusting of various metals, aging and chemical change of paints and coatings on the spacecraft, and fracturing of O-rings. The solutions to these concerns are as varied as the parts themselves.

The spacecraft is very sensitive to temperature, humidity, and magnetic fluxes, and suitable precaution is exercised in the "clean room" in the JPL Spacecraft Assembly Facility, where Galileo will be stored until shipment to the Kennedy Space Center. Even so, exposure to the atmosphere may corrode some of the magnesium alloys used on the spacecraft. (Such metals would not corrode in the vacuum of space or within Galileo's original lifetime.) Quality assurance personnel will visually inspect all surfaces before shipping the spacecraft.

In the case of the paints on spacecraft parts, periodic visual inspections are conducted to verify that the paint is not flaking, cracking, or peeling. So to, some of the coatings on spacecraft parts may shrink over time, damaging the parts they were used to protect. Both uralane and humiseal conformal coatings on the electronics are being studied and monitored to avoid any damage. Reliability tests will continue on the electronic parts themselves to verify their continued effectiveness.

Fracturing of O-rings occurs after long-term storage and disuse. To circumvent this potential problem, engineers will "exercise" all parts containing O-rings every six months.

Springs, which were compressed for release of systems such as the magnetometer boom, may suffer degradation after such long storage. All preloaded springs will be inspected for signs of stress.

A further problem involves the tests themselves. Personnel will need to handle the spacecraft to conduct the tests, and this contact may add dirt to surfaces or overstress flexible parts. Visual inspections and testing care will be ongoing to avoid this dilemma.

Meet the Team

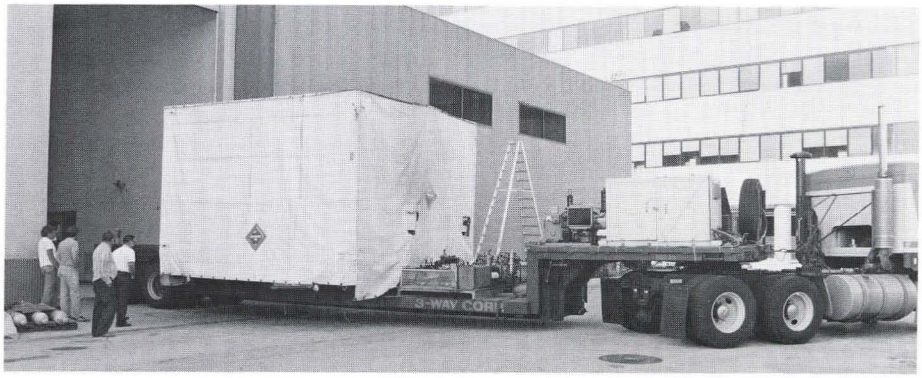
Probe Operations Office Chief Benny Chin is a commuting member of the Galileo team. He divides his time between his home base of the Ames Research Center and roughly one day a week at the Jet Propulsion Laboratory.

During some quiet moments between a project review and the flight north, Benny outlined the biggest jobs his office is dealing with now. They all stem from rescheduling the mission. For example, choice of the VEEGA trajectory means that new system studies must be done to check for any heat problems when the spacecraft approaches the orbit of Venus. Sequences of activities must be changed. Finally, and most importantly, the shelf life of all the parts must be checked. "A lot of these things were built prior to 1980, and we're looking at a baseline 1989 launch plus a six-year mission!"

Getting these jobs done means that studies must be made by scientists at a lot of sites. Coordinating those studies requires a lot of travelling. Fortunately, Benny has grown accustomed to such travelling. He has been doing spacecraft testing and operations for Ames since 1968, first with Biosatellite, Pioneer Jupiter, and then with Pioneer Venus. During that time he has been involved in seven launches. Before becoming Probe Operations Chief in March 1986, he was involved in integration and test of the Probe, and he was at Kennedy Space Center preparing for launch.

Benny ascribes much of his ease with travel to growing up in the New York City area (mostly East Orange, New Jersey). Getting away from that small world started with an aerospace bachelor's degree at Virginia Polytechnic Institute and continued with a two-year stint at the Pacific Missile Range, 21 years service at Ames, and an MBA from Golden Gate University.

At the end of the spacecraft's testing at the Cape, Galileo was shipped back to JPL. The Orbiter and Probe arrived here in good shape on February 21, 1987, after a 5-1/2-day trip from Florida. The spacecraft underwent about a month of thermal blanketing development work, after which system baseline tests to verify its condition after shipment were made. Starting March 23, a series of special tests began to resolve problem areas. All VEEGA-mission modifications will be completed by April 1989, prior to the spacecraft being returned to the Kennedy Space Center for preparation for shuttle launch in October or November 1989.

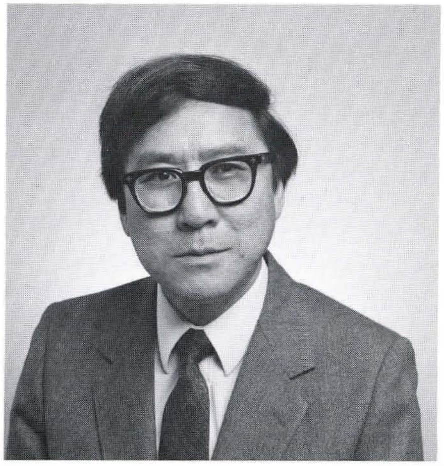


A second match with the job is in dealing with people. The soft-spoken Probe "Ops" Chief enjoys "getting out and interacting with people," a key part of running a scattered operation. He even commented that sitting behind a desk five days a week would probably not be enjoyable for him.

Integration and testing and operations have been the main parts of Benny's career at Ames ("with steadily rising levels of responsibility"). In his words, "I just fell into it when I arrived, and I liked it." When asked about a goal ten years in the future, the answer came with calm assurance: "We will have completed this mission and be into another one, either in operations or management."

Benny lives in Saratoga (west of San Jose) with his wife Winnie and two children, Kristen (10) and Matthew (7). Other than a little skiing in the Sierras, his main hobbies are " . . . taking care of the kids."

— *Roger V. Carlson*



Benny Chin

Editor . . . . Jeanne Collins

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Jet Propulsion Laboratory
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Pasadena, California

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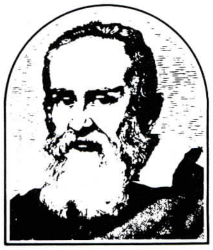

The Galileo Messenger

Issue 20 August 1989

From the Project Manager

With Magellan's successful launch in May, attention is now being focused on Galileo's long-awaited launch opportunity, scheduled for October 12, 1989. How fitting that it falls on Columbus Day. Galileo, also known to some as the "critter," will then be aboard the STS-34 Space Shuttle Atlantis and finally on its way to Jupiter!

In January and again at the May 6 "Galileo Day" we had the pleasure of meeting the STS-34 astronauts. The Atlantis crew will fly under the command of Captain Donald E. Williams with Commander Michael J. McCulley as our pilot; Shannon W. Lucid, Franklin R. Chang-Diaz, and Ellen S. Baker will be the mission specialists. Each of these individuals brings a diverse background to the success of the mission.

Galileo's 1989 VEEGA (Venus-Earth-Earth Gravity Assist) mission offers a wealth of unique scientific opportunities. On February 9, 1990, Galileo will fly by Venus, where we will be studying its lightning, atmospheric dynamics, and cloud composition. Then, in December of both 1990 and 1992, Galileo will have two Earth encounters. During these encounters, we will have an opportunity to observe Earth's geotail, hydrogen corona, and global meteorology, as well as new areas of our Moon and determine the composition of unsampled areas.

In October 1991, Galileo will have the opportunity to be the first spacecraft to encounter an asteroid, Gaspra, and may also fly by Asteroid Ida in August 1993. These passings will allow Galileo to examine the surface geology, composition, size, shape, and mass of the asteroids, and analyze the relation of primitive bodies to meteorites. During its six-year journey to Jupiter, Galileo will also be making measurements of the interplanetary environment,

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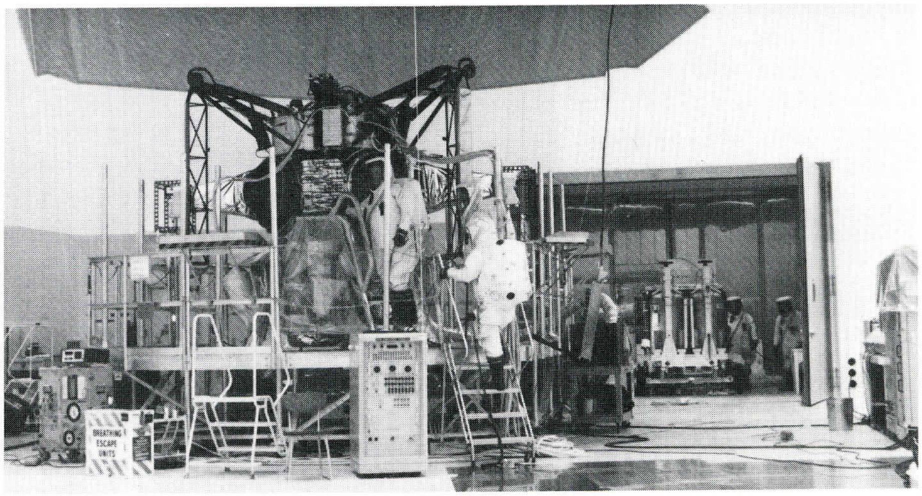


Test and integration activities are drawing to a close at Kennedy Space Center as Galileo nears launch. Above, workers are loading the Retropropulsion Modules with propellant.

Happenings at the Cape

Excitement and exertion are playing a balancing game with Galileo's team at the Kennedy Space Center. Excitement grows over the scheduled October 12 launch of the Galileo spacecraft, which for some is a culmination of 15 years of work. And, exertion increases with the remaining test and integration activities necessary to complete in these last few months before launch.

Those activities have kept the team members busy in Florida, where they have completed Phase 1 of the work there -- preparing Galileo for launch in the payload processing facility. Milt Goldfine, who leads the team at the Cape, explained, "Phase 1 was the most technically challenging part of our operations. With Phases 2 and 3 (integrating the spacecraft and the IUS together and then with the shuttle), we have fewer activities to accomplish in a greater period of time."

The Galileo team members have been getting excellent support from their KSC counterparts. With everyone working diligently, all the activities to ready the spacecraft and the Space Shuttle Atlantis are running on schedule.

Integration will continue until August 23. At that time, the Galileo spacecraft, mounted atop the IUS, and loaded into the payload bay of the Space Shuttle Atlantis, will be moved onto its launch pad, awaiting the October morning it will thunder its way to Jupiter.

The PPR: Finding That There Is More Than Meets The Eye

In aerial photography, comparing different colors can highlight ground features that cannot be seen otherwise. Similarly, the Galileo Orbiter has an instrument that views an assortment of spectral bands. The Photopolarimeter-Radiometer (PPR) is in many respects three instruments combined into one: a photometer, a polarimeter, and a radiometer. Combining three major functions into one instrument makes a flexible and powerful experiment, but it required some compromises and a great deal of clever design.

Investigating

The PPR will determine the amounts of radiation at Jupiter and its moons, provide atmospheric temperature profiles in the topmost (smog-like) layer and in the stratosphere just below, and help us understand cloud and haze properties and structures.

At Jupiter, the Probe will measure the atmospheric conditions in its path. PPR data for each area will then be compared with remotely sensed data for the entire planet.

Like Galileo's Ultraviolet Spectrometer and Near Infrared Mapping Spectrometer, the PPR is aligned with the imaging system. That way, data from all three instruments can be correlated for the object being viewed and can be used to investigate major elements of the Jovian atmosphere.

Performing

A detailed look at the tasks performed by each of the PPR's functions starts with the Photopolarimeter, whose design comes almost directly from the cloud photopolarimeter on the Pioneer Venus Orbiter.

Cloud particles can play a dominant role in determining the polarization of reflected sunlight. (Polarization is the suppression of the vibration of light waves in a certain direction.) For instance, water droplets in the Earth's atmosphere produce rainbows with a very strong signature in the polarization as a function of the phase angle (the angle between the Sun, the water droplet/scatterer, and the observer).

Scattering due to the molecules of an atmosphere (Rayleigh scattering) produces a very distinctive polarization signature and is most prominent at shorter wavelengths. (It is this wavelength dependence that makes the sky appear blue on Earth.) An examination of the relative contribution of Rayleigh scattering provides an estimate of how much gas is above the cloud tops. This "optical barometer" technique helps to see variations in the height of the cloud tops associated with major Jovian cloud features. The Photometer investigates at seven narrow bands in the visible and near infrared wavelengths. These channels correspond to the positions of several absorption bands which are due to atmospheric methane and ammonia. The behavior of the intensities of these bands across Jupiter will help deduce the vertical structure of clouds and haze.

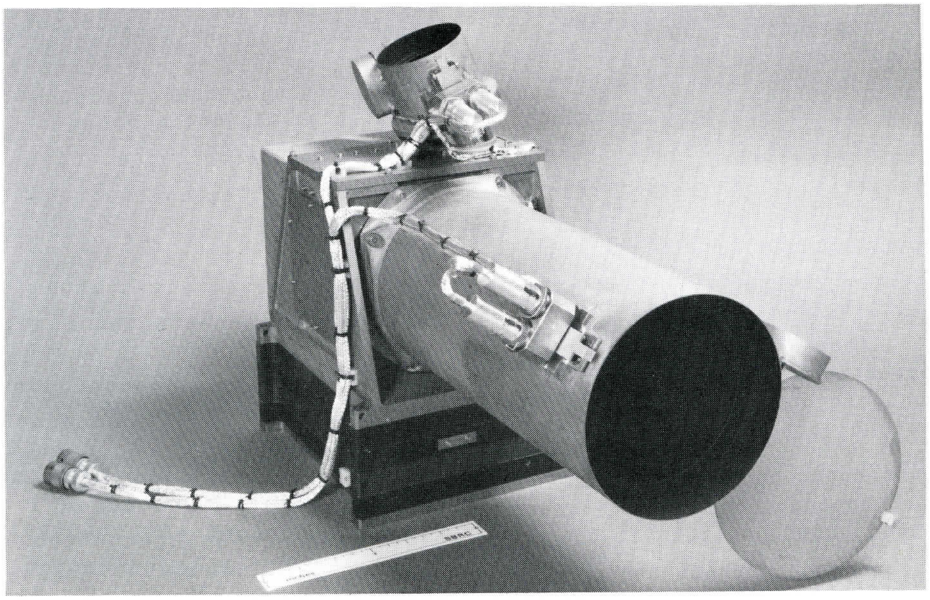
The Radiometer's infrared wavelengths overlap some of those used by the Probe's Radiometer. They correspond to regions (mainly hydrogen) with different atmospheric absorption, that way the Radiometer can see to different depths and measure each region's brightness temperature.

The PPR has two additional radiometry bands. One of these uses no filter and, thus, observes all radiation from the visible through thermal and solar infrared wavelengths; the other lets through solar radiation only. The difference between the solar-plus-thermal and the solar-only channels gives the total thermal radiation emitted.

For viewing the moons of Jupiter, this Radiometer is the only source of data on direct "temperatures" of the surface. It is expected to be able to make such measurements for many regions, including the interesting "hot spots" near the volcanoes of Io.

Constructing

A 10-centimeter (4-inch) diameter telescope collects the radiation for all three functions of the PPR. Light from the telescope is focused through one point, giving all three functions exactly the same field of view. The light then strikes a filter/retarder wheel, which can step through 32 positions.



The PPR measures a scant half-meter from end to end.

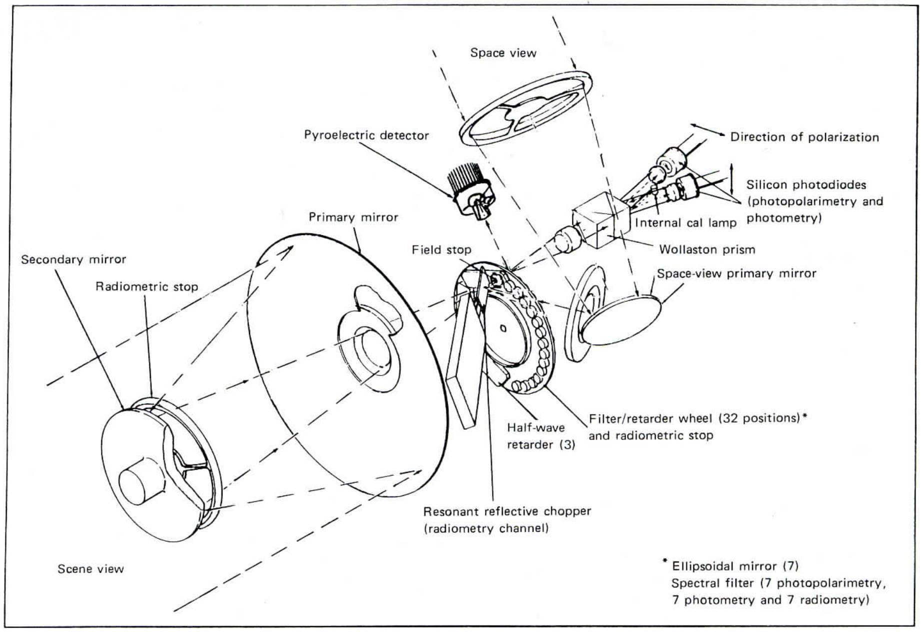
A single polarimetry observation requires three wheel positions, each with a filter and a half-wave retarder. After passing through these, the light enters a prism, separating it into beams of vertically and horizontally polarized components. These beams are directed to a pair of photodiode detectors. (These detectors measure the light by converting it into electricity.) Thus, the polarization of the incoming light is determined by rotating the beam itself using the retarder.

Photometry, in which just the intensity of the incoming light is measured, requires only one position on the wheel with an appropriate filter. In principle, this filtered beam could be immediately directed to a detector to measure its intensity. The PPR, instead, passes the beam through a prism and to the silicon detectors used for polarimetry, thus, avoiding the added complexity of an additional optical path and detector. The photometry intensity is then just the sum of the intensities measured by the two detectors.

Another advantage of this design is that some information on the polarization of the observed light is available if the polarization direction is known or inferred from other measurements.

For radiometry (measuring thermal infrared radiation), a separate telescope allows radiation to come in from space (corresponding to a 3 Kelvin blackbody) to provide a reference signal. This beam intersects the incoming light's path just ahead of the filter wheel. Filters are used to select the desired wavelength; then mirrors send the beam to the side. There, it strikes a conical mirror that focuses it onto a pyroelectric detector.

For radiometric calibration, there is a target on Galileo's sunshade, which can be viewed and its temperature monitored by means of platinum resistance thermometers connected to the PPR's electronics. Similarly, the Photometer's response can be checked with an internal calibration lamp.



Light enters the PPR from two different angles and follows a complex path to one of two detectors.

Integrating

Trade-offs were crucial to the PPR's design. An actively cooled radiometry detector would have been more sensitive, but would have been incompatible with the photometry and polarimetry requirements. Also, one instrument splitting time among three functions has, of course, less time for any one of them. However, there is a tremendous advantage in having the functions and wavelengths sampled with exactly the same field of view. Despite all its capabilities, the PPR has a mass of only 5.0 kilograms and is less than 0.5 meter on its longest axis. It uses a peak power of 11 watts and an average of 6 watts.

The PPR was designed and built at the Santa Barbara Research Center (SBRC) in California. The SBRC has supplied sensors for Landsats and weather satellites and has built radiometers for many deep space missions.

J.E. Hansen, the Principal Investigator for the PPR, is at the Goddard Institute for Space Studies in New York City, as are investigators M.D. Allison, A.D. Del Genio, A.A. Lacis, W.B. Rossow, and L.D. Travis. Other investigators include G.S. Orton and T. Martin at JPL, P.H. Stone at the Massachusetts Institute of Technology, Y.L. Yung at the California Institute of Technology, and D. Morrison at the University of Hawaii.

-- Roger Carlson

(Continued from page 1)

including the distribution of hydrogen in the inner solar system, dust particle characteristics throughout the solar system, measurements of the solar wind, and searches for gravity waves. Some of these data will be collected for the Galileo scientists by our German colleagues using the Weilheim tracking station near Munich.

With the launch delay, problem solving, and VEEGA mission changes and their impact on the spacecraft's hardware and software, our collective ingenuity and dedication have been exhaustively tested. I commend each of you for your excellent performance in the face of these challenges. JPL can be very proud of the achievements and accomplisments we have made. The time remaining before launch, as well as the mission, should be most exciting and rewarding for everyone on the Galileo Project

-- Dick Spehalski

Meet the Team

Galileo Chief of Test and Operations, Milt Goldfine, and his team of "free spirits" are responsible for assembling, testing, and launching the Galileo spacecraft. The enthusiasm and expertise which Milt brings to his job have helped to make JPL's spacecraft testing program one of the finest in the aerospace industry.

Milt came to JPL with a background in mathematics from Hunter and Columbia Universities. Before college, Milt served in the Army/Air Corps during World War II, and after graduation he worked for PhilCo for two years. JPL, however, has captivated him since 1954, when he came here to work on the Corporal missile. Over the next several years, Milt searched for suitable sites for the Microlock system (the predecessor receiver of the Deep Space Network), worked on the Re-entry Test Vehicle (the forerunner of Explorer I), and helped test the Sergeant missile at the White Sands Test Facility. He returned to Pasadena to become Test Chief for Rangers I and II. Milt worked through the Mariner and Galileo Projects, and aided the Seasat radar experiment in its testing phase.

–Milt Goldfine

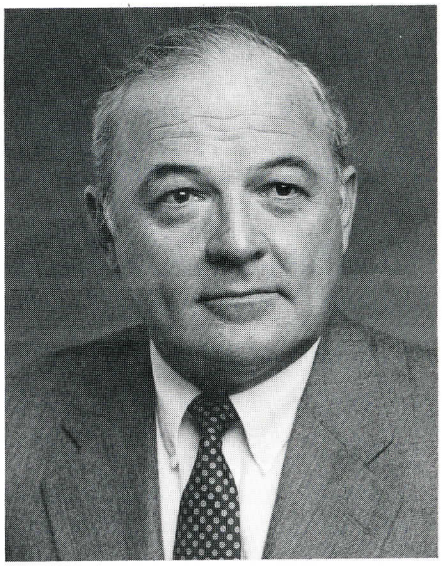
JPL's spacecraft testing is unique since the scientists and engineers who develop a subsystem support the spacecraft's testing, rather than transferring the testing to another organization. Milt and his team coordinate all of Galileo's test and launch activities.

"The Test Team and I find the tasks are very challenging and the work gratifying. Equipment and software delays and other problems have to be accommodated for Galileo's fixed launch period," Milt stresses. "One of the nice things about the job is the great exposure Test Team members have with the rest of the Lab and the Galileo scientists." He emphasizes that the cooperation of the groups supplying Galileo's hardware and software is essential for successfully launching on time.

The Test Team activities he directs start at the Spacecraft Assembly Facility (SAF) and conclude with launching the spacecraft from Kennedy Space Center (KSC). Milt and several Test Team members accompanied the spacecraft to KSC this May. Meanwhile, the remainder of the Team is staying at JPL for real-time data analysis of the tests conducted at KSC.

Milt emphasizes his debt to the individuals in the test and operations area. When the launch was delayed, Milt petitioned the Project to hold over the men and women who were working there, "I felt that the expertise in the test area was invaluable and, because the Project wisely maintained this group through the down period, we are now able to smoothly proceed into the VEEGA mission."

Through all his projects, his wife, Jeep, has helped him to persevere and to keep his optimistic attitude. Their son, Bernie, is a teacher. In his spare time, Milt plays handball, reads, works with his computer, and experiments with high-fidelity digital recording on high-quality videotape.



–Dick Spehalski

Editor's Note

Since the last Messenger, *the management of the Galileo Project has changed hands. The new Galileo Project Manager is Dick Spehalski; John Casani, the former Manager, is now the Assistant Laboratory Director of the Office of Flight Projects.*

Dick "Spe" Spehalski came to JPL from Cornell in 1959. He was the Galileo Flight System Integration Manager before being promoted to Galileo Project Manager. Prior to joining Galileo in 1977, he was the Applied Mechanics Division Representative for Voyager, from inception through launch. His earlier experience began on the Sergeant missile system and continued through the Mariner Venus and Mars missions.

Dick and his wife, Nancy, live in Altadena and have raised three sons, Steve, Mark, and James. An avid sports fan, he likes to spend his spare time fishing, boating, and camping with his family. He also plays handball several times a week and tinkers with his Corvair.

Editor.......... Jeanne Collins
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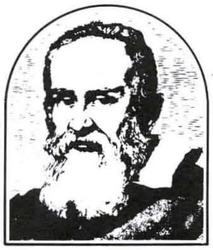


The Galileo Messenger

Issue 21 | November 1989

From the Project Manager

The launch of the Galileo spacecraft, that momentus event on which our collective energy was focused for such a long time, is now history. We shall continue to look forward to the many tasks that must be successfully accomplished to obtain the scientific knowledge that we seek from the Galileo mission. However, the act of launching and successfully achieving our flight path to Venus is of such significance that it merits some special attention while it still lingers in our memories.

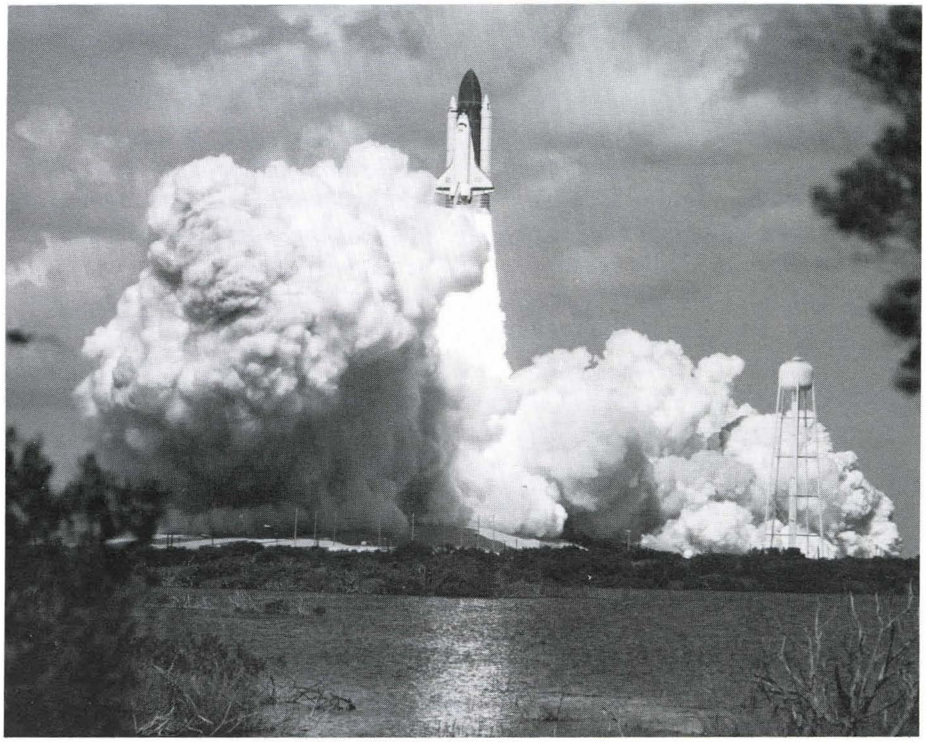
The Galileo launch, to many of us, represents a culmination of years of personal and team efforts and of sacrifices. The emotions present within each of us at such an event defy description. To some, the launch represents the completion of a challenging spacecraft development, to others the start of an exciting mission. To many, it is a shift from one to the other, but nevertheless a soul-stirring event.

From my perspective as Project Manager, I was fortunate to witness the coming together of such a diverse set of activities that it boggles the mind. The professionalism, teamwork, and dedication visible in this process was truly inspiring to behold.

To those of you that will not continue the mission with us, I thank you and wish you great success in your future endeavors. To those continuing on with us, I am certain we will have challenges to fully exercise our talents. To all, I thank you and wish you Godspeed.

— *R. J. Spehalski*

Launch at Last!



Launch to Landing

At 9:54 A.M. Pacific Daylight Time (PDT), on October 18, the Space Shuttle Atlantis was launched under a sky filled with puffy, white cumulus clouds. The Galileo spacecraft, destined for Jupiter, began its six-year journey.

At the Kennedy Space Center and at JPL, Flight Team members and their families nervously watched the launch. Applause erupted at the moment of lift-off and again as the Solid Rocket Boosters separated from the Shuttle. As the mission progressed, tension was visibly released.

It seemed as though Galileo was fated to be delayed. Worries over whether Hurricane Hugo would come onshore at the Kennedy Space Center mounted until, at the last moment, the destructive force of the storm swept north of the launch site. Engineers relaxed as the decision to leave Atlantis and Galileo on the launch pad proved to be well-founded.

As the first day of the launch period approached, excitement mounted on both coasts as the long-awaited day neared. On Monday night, October 9, technicians discovered a glitch in the Shuttle's second main engine controller. The decision was made the next day to replace the faulty computer, thereby delaying the

scheduled October 12 launch until sometime the following week.

The new lift-off date of October 17 looked good all around. The Shuttle was performing well, Galileo was nestled in its payload bay, and the astronauts boarded Atlantis. As time passed, however, the clouds began to multiply. Countdown continued until the last possible second, when the Launch Director scrubbed the launch because of the inclement weather. Weather conditions around the globe can affect the Shuttle's lift-off because, if the Shuttle needed to return to the Earth shortly after launch it could do so at several sites: Ben Guerir, Morocco; Moron, Spain; Banjul, The Gambia; Edwards Air Force Base, California; White Sands Space Harbor, New Mexico; or at KSC itself. Because of the inclement weather at the Cape, that landing site was not available and the launch was delayed again.

As the Galileo team looked forward to launch the next day, disaster struck Northern California. A 7.1 earthquake, centered just 15 miles south of Sunnyvale, caused evacuation of the Inertial Upper Stage (IUS) control center there, which was crucial to mission operations. The crew recovered as the night progressed and JPL was receiving the required data as launch neared.

Even as the moment of final launch approached, the clouds looked ominous over the Kennedy Space Center. However, at last, nature cooperated and STS Mission 34 was under way.

At about 4:15 P.M. PDT, Mission Specialist Shannon Lucid initiated Galileo's deployment. As deployment finished, STS-34 Commander Donald E. Williams declared, "Galileo is on its way to another world. It's in the hands of the best flight controllers in this world — fly safely."

One hour later, the IUS rocket ignited, propelling Galileo toward its first encounter, Venus. As the second stage of the IUS fell away from the spacecraft, Galileo was finally on its own, its destiny in the hands of the Flight Team.

It seemed to be a mission of accomplishment in the face of adversity. Even after deploying the spacecraft, the landing proved to be a concern. Heavy winds were forecast for the California desert, and so the landing time was accelerated by two orbits (three hours). An hour or two before landing, the fog was rolling off the hills into the dry lake bed. Then, the skies cleared just before the Shuttle was scheduled to land. As the Space Shuttle Atlantis touched down in a picture-perfect landing at Edwards Air Force Base, the crowds cheered. It was a strange blend of viewers — Galileo Flight Team members, reporters, a host of people (some of whom had retired years ago) who had at some time helped to design and construct Galileo, and, most important, the American public who paid for the mission.

The Acting Associate Administrator for Space Flight summed up the feelings of many, "Galileo is on its long, multiyear odyssey to Jupiter. Before, we have gotten a fleeting glimpse [of Jupiter]. This time we will be stopping. This is the real crowning accomplishment of this mission, to get Galileo on its way."

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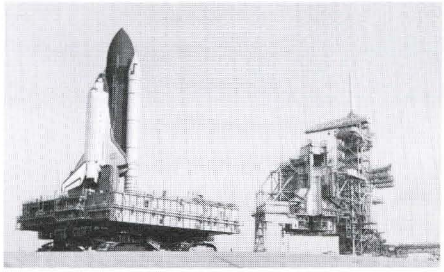

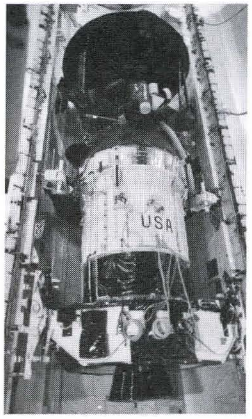

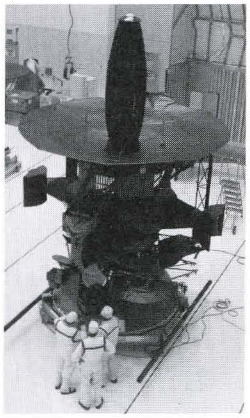

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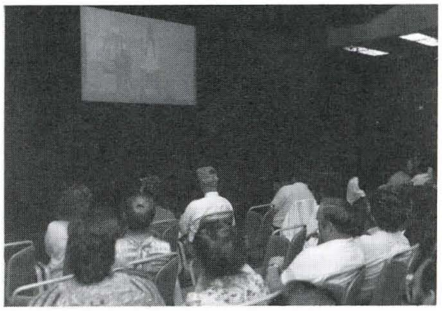

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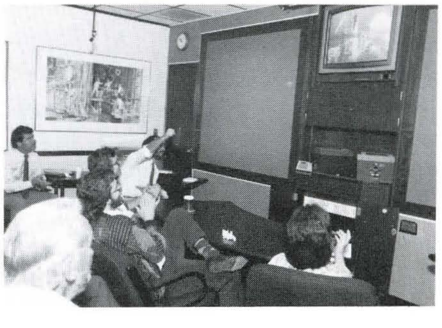

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1 Atlantis, with Galileo loaded on board, was wheeled to Launch Pad 39 to await the October launch.

2&3 Preparations at Kennedy Space Center proceeded smoothly. The spacecraft underwent final check out and loading into the payload bay of the Space Shuttle Atlantis.

4 The STS-34 astronauts, shown here walking away from their jets, commuted between the Kennedy Space Center in Florida and Johnson Space Center in Houston.

5–8 Flight Team members and their families were on the edges of their seats as Galileo launched into the October skies.

Galileo: Up to Date

The Galileo spacecraft is performing without a significant flaw. Just a few days after the Shuttle Atlantis propelled Galileo on its way to Jupiter, the Mission Operations Team began sending commands to the spacecraft. As of October 27, over 250 commands had been sent to the spacecraft in "real time." In general, the spacecraft is operated using sequences transmitted from the ground and stored for later execution. Real-time commands, however, are transmitted on an as-needed basis to change the content of the spacecraft's memory.

"The Heavy Ion Counter is powered on and is detecting high-energy ions from solar flares," stated Matt Landano, Deputy Mission Director. These solar flares are energetic enough to cause single event upsets (SEUs) in sensitive equipment. However, there have been no SEU events detected by Galileo. SEU incidences, which plagued earlier spacecraft, were analyzed by the Project and specific design changes were made, consisting of shielding and hardened electronic components.

The Solid-State Imaging and Near Infrared Mapping Spectrometer instruments were both successfully checked out in late October. Data from these activities were stored on the Data Memory Subsystem tape recorder and played back later, consistent with telemetry link capabilities. When Galileo encounters Venus, Earth, the asteroids, and Jupiter, it will make extensive use of the tape recorder to capture precious science observations. The Energetic Particle Detector (EPD) instrument cover is open and its protective sunshade is in place. The Retro Propulsion Module 10-newton thrusters were fired and monitored as part of its periodic maintenance plan, and showed temperatures ranging from 66°C to 112°C, well below the 150°C limit.

The spacecraft is tracked by the Deep Space Network (DSN) system of antennas located in California, Australia, and Spain. Overall, the support from the DSN has been splendid. However, minor problems have occurred at the Madrid, Spain station. Two hardware failures and an antenna pointing error have caused the Flight Team to work around problems without any significant loss of data. In addition, the German Space Operations Center successfully received both high- and low-rate data at S-band via its Wilheim tracking station.

What awaits Galileo over the next few months? Spacecraft characterization will continue, especially the Attitude Control Subsystem, in support of the first Trajectory Correction Maneuver planned for early November. Later the remaining science instruments will be checked out for the Venus flyby. "We plan to turn on all the instruments for the Venus flyby in February," Landano went on to explain. "However, we will be very cautious not to jeopardize the health of the Plasma, EPD, and Plasma Wave Spectrometer instruments due to the intense solar thermal environment near Venus."

Checking Out the Probe

Shortly after launch, the Flight Team began systematically checking each of the spacecraft's systems and subsystems to make sure all were functioning properly. The first system checked out was the Probe.

"We wanted to verify the health and safety of the Probe," explained Pat Melia, Probe Engineer for Ames Research Center, which manages the Probe project. During launch activities, vibrations from Atlantis and the Inertial Upper Stage booster rocket could have "flipped" some of the electrical relays, turning on relays which should have remained off. If that had happened, some of the systems on board the Probe could have begun draining the limited resources of its lithium battery. Because this battery is not rechargeable, this checkout was extremely important. Without power at Jupiter, the Probe would not have been able to function.

The Systems Functional Test (step two in a three-step checkout) showed flawless results. None of the relays had been flipped. If they had, mission operations personnel would have been able to easily correct the problem from the ground. Such tests are planned annually during cruise, with the next test scheduled during the first Earth flyby, in December 1990.

In addition, the Probe checkout afforded an opportunity to pump out any gas which might have accumulated around the Neutral Mass Spectrometer (NMS), one of the Probe's six science instruments. The NMS will help to determine the chemical constituents of Jupiter's atmosphere. After the checkout was completed, the Probe was turned off.

*Galileo Mission Summary**

Distance from the Earth	3,041,000 kilometers (1,890,000 miles)
Distance from Venus	149,069,000 kilometers (92,627,000 miles)
One-Way Light Time	10 seconds
Velocity Relative to the Earth	9.93 kilometers per second (8800 miles per hour)
Veolicty Relative to the Sun	26.72 kilometers per second (59,000 miles per hour)
Spacecraft Sun Angle	9.6° off Sun
Spacecraft Spin Rate	2.89 revolutions per minute
Downlink Telemetry Rate	7.68 kilobits per second (low rate)
Spin Configuration	All spin
Powered Science Instruments	Heavy Ion Counter and Magnetometer
RTG Power Output	570 watts

*all information is as of October 27, 1989

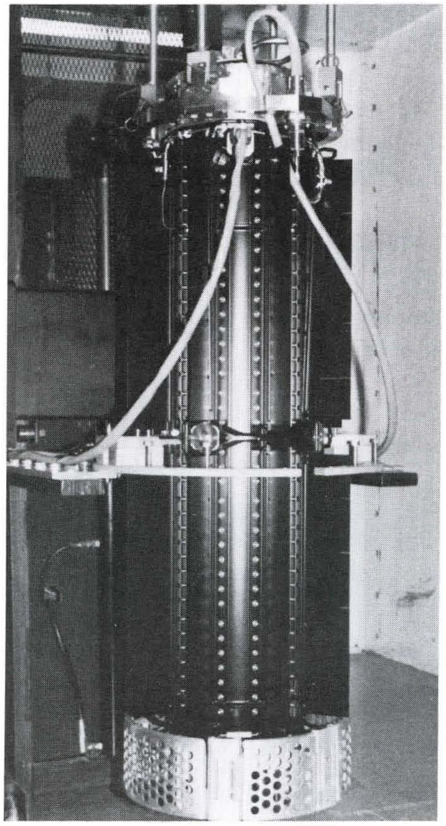
What's in an RTG?

Once at Jupiter, Galileo will begin an exhaustive study of the Jovian environment. This furious activity will test the limits of Galileo's Flight Team, as well as its hardware. In spacecraft terms, a great deal of energy will be required to run the instruments with which Galileo will probe the Jovian depths. In the past, spacecraft that travel at or within Earth's orbit have utilized solar energy to power their instruments. However, at the great distance of Jupiter, the only feasible power source involves the use of Radioisotope Thermoelectric Generators (RTGs).

The RTGs power the spacecraft through the radioactive decay of plutonium-238. This decay emits heat, which is converted into electricity for the spacecraft to "see, sense, hear, and speak." This power supplies a reliable, long-lasting source of electricity that is insensitive to the chilling cold of space and virtually invulnerable to high radiation fields, such as Earth's Van Allen belts and Jupiter's magnetosphere.

An RTG consists of two parts: a source of heat and a system for converting the heat to electricity. The heat source contains a radioisotope, such as plutonium-238, that becomes physically hot from its own radioactive decay. This heat is converted to electricity by a thermoelectric converter that uses the Seebeck effect, a basic principle of thermoelectricity discovered in 1822. An electromotive force, or voltage, is produced from the diffusion of electrons across the joining of two different materials (like metals or semiconductors) that then form a circuit when the ends of the converter are at different temperatures.

Each RTG contains 18 separate heat source modules, and each module encases four plutonium-238 pellets. The modules are designed to survive a range of postulated accidents: launch vehicle explosion or fire, reentry into the atmosphere followed by land or water impact, and post-impact situations. An outer covering of graphite provides protection against the structural, thermal, and eroding environments of a potential reentry. Additional graphite components provide impact protection, while iridium cladding of the actual fuel cells provides post-impact containment. The fuel is in the form of plutonium-238 dioxide, a ceramic material that is resistant to fracturing.



One of Galileo's two RTGs undergoes some of the myriad tests for safety and operations.

As the launch of Galileo neared, antinuclear groups, concerned over what they perceived as risks to the public safety from Galileo's RTGs, sought a court injunction prohibiting Galileo's launch.

From the outset, the Project understood the need to safely operate an RTG-powered spacecraft and had developed appropriate safety-related data. The RTGs themselves were carefully designed and extensively tested. And, in fact, RTGs have been safely used for years in planetary exploration. The Lincoln Experimental Satellites 8/9, launched by the Department of Defense, had 7% more plutonium on board than does Galileo, and the two Voyager spacecraft each carried 80% of the plutonium Galileo does.

After the Challenger accident, a study considered additional shielding. Additional shielding was not adopted, even though it would offer some protection near the launch area, because the great complexity of such a design significantly increased the risk of mission failure. If a failure on orbit occurred, additional shielding would significantly increase the consequences of a ground impact. The two close flybys of Earth had raised questions about the possible inadvertent reentry of Galileo into Earth's atmosphere.

Exhaustive studies were made by JPL and were independently reviewed regarding the safety of the Venus-Earth-Earth Gravity Assist (VEEGA) mission. These studies showed that the Galileo team had designed the spacecraft and its trajectory to keep the probability of an inadvertent reentry at Earth to less than one in two million. Over the course of the Project, millions of dollars were spent to improve the safety of shuttle flights and the Galileo mission. The Department of Energy, as required by law, completed a mission risk analysis, with full disclosure of those results to State and local governments. The Interagency Nuclear Safety Review Panel completed an independent Safety Evaluation Report, and the Office of Science and Technology Policy approved the mission. As a result of the Project's testing and rationale for the Galileo mission, the Court found in the Project's favor and the launch was a splendid success.

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Space Administration

Jet Propulsion Laboratory
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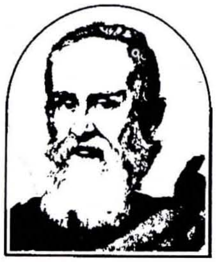


The Galileo Messenger

Issue 22 February 1990

From the Project Manager

After cruising through the solar system for three and one-half months, the Galileo spacecraft is about to complete a very important milestone—the flyby of Venus. The celestial dynamics of this planetary visit are required to attain our primary goal, reaching Jupiter, but Galileo will also take a close, scientific look at our planetary neighbor.

We intend to perform an encounter sequence, with all science instruments gathering data. Unfortunately, the results will not come back to Earth immediately because our high data rate capability is limited The high-gain antenna cannot be used because it must be protected from the intense sunlight at Venus. Rather than sending the information back right away, the data will be stored on board Galileo for transmission to Earth in October, when our telecommunications performance has improved. Fortunately, due to some onboard data manipulation, we do expect to have a few images and NIMS data available on Earth several days after encounter.

We are about to complete our first planetary step to Jupiter—symbolically putting the V in VEEGA (Venus–Earth–Earth gravity assist). The Venus assist places us on an Earth-return trajectory, and provides Galileo

—see page 4

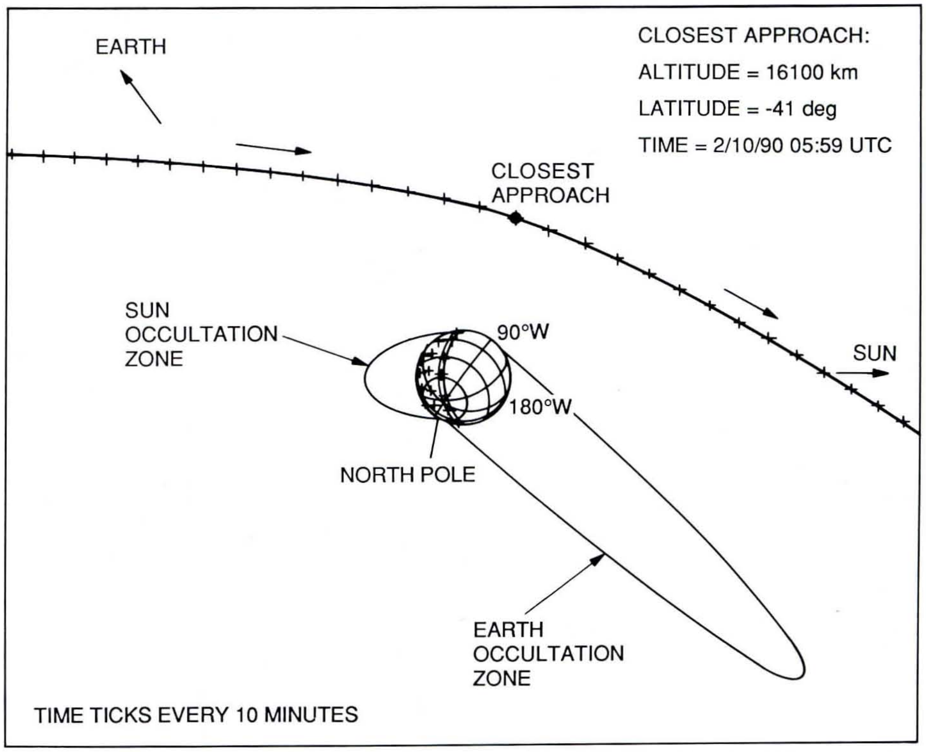
Galileo's First Encounter: Venus is in View

The Galileo Team is studying a variety of goals for the Project—some are occurring as you read this, others will occur years from now. Just one of the many wonders in Galileo's bag of tricks is the upcoming flyby of Venus.

Since its launch, the Galileo spacecraft has performed marvelously. Both its hardware and software are surviving the rigors of the increasingly hot environment quite well as Galileo nears its February encounter with cloud-enveloped Venus. The Project, in reviewing the advantages and concerns of the Venus encounter, realized that Galileo will be a pioneer in several ways at this way station on its route to Jupiter.

For instance, Galileo will be the first spacecraft to map the planet in the infrared wavelengths, seeing the clouds as well as unveiling the surface beneath. For the first time, researchers will also view small-scale features at the mid-latitude and equatorial regions and perform spectroscopy of the middle and deep layers of the thick Venusian atmosphere. The bulk of these science data will be obtained by the Near-Infrared Mapping Spectrometer (NIMS), an

—see page 4



On February 9, Galileo will sweep past Venus. Closing to within 10,000 miles of its misty atmosphere, Galileo will get a gravitational assist on its way to Jupiter.

Galileo: Up to Date

The Flight Team and the Galileo spacecraft have been busy with a multitude of spacecraft characterization activities, two Trajectory Correction Maneuvers (TCMs), and a major checkout of the science instruments in preparation for the upcoming Venus encounter.

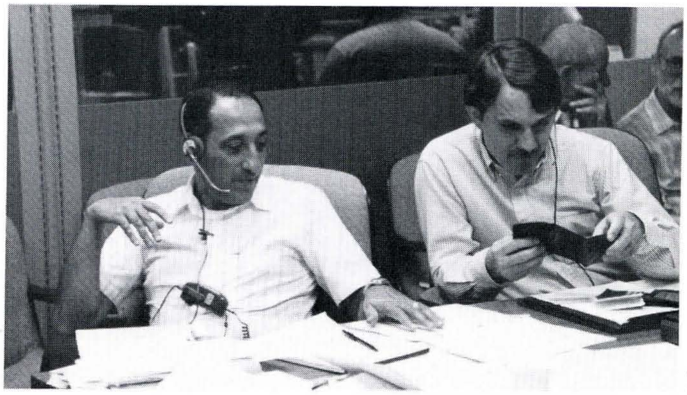
The first TCM took place from November 9 to 11. To aim Galileo toward its February 9 rendezvous with Venus, the mission controllers commanded firing of the Retropropulsion Module (RPM) 10-Newton thrusters. The thrusters, located on Galileo's spinning portion, were fired over a limited spin angle so as not to degrade or damage the sensitive instruments and components on the spacecraft. In addition, the mission controllers used the short-burst, *benign, pulsed* firings to ensure that the thrusters did not exceed safe temperature limits, a possibility with longer lasting firings. During TCM1, in fact, one of the thruster temperature sensors erroneously indicated an overheated condition; as a precaution, the mission controllers selected the backup thruster and successfully completed the maneuver.

In total, over 2000 pulses were required to complete TCM1. A second TCM was successfully completed on December 22; a total of about 30 TCMs will be necessary before the the spacecraft reaches Jupiter in December 1995.

Minor spacecraft surprises have arisen, but the Orbiter Engineering Team has dealt with each in turn. Some of these surprises included a slightly larger than expected wobble, a somewhat unexpected operation of the RPM pressure regulator, and about a 15°C cooler than expected Dust Detector temperature. Galileo's solar shades are all performing well and keeping the spacecraft within the acceptable temperature range as it approaches the intense heat near Venus.

Galileo successfully performed an intensive four-day science checkout activity during the last week in December. All of the Orbiter's science instruments were powered on and used to collect data. Preliminary analyses of these data indicated that all the instruments are functioning properly.

The Galileo spacecraft is now in a "safed" condition after the system fault-protection safing algorithms were automatically executed on January 15. Fault protection, in general, is *triggered* when out-of-normal limit conditions occur on the spacecraft. Such conditions may be caused by an actual element or sensor monitor failure, or a computer input error or failure. Galileo's fault protection responses are designed to restore system functionality. During noncritical mission periods, the fault-protection puts the spacecraft into a safed mode and awaits instructions from the ground.



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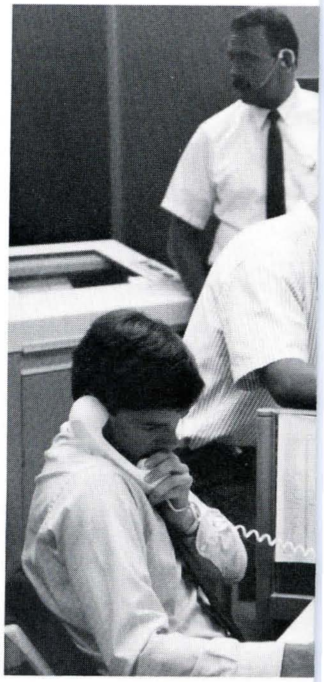

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Galileo's Flight Team
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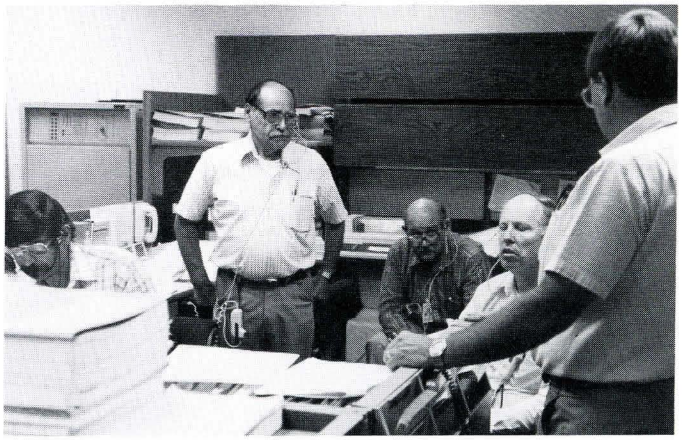
The Flight Team mem
Zipse; 2. Tom Fogle, Pam
4. Curt Henry, Pete Kobe
6. Hamid Kuri, Al Shain,
Kobele, Charlie Barbar,

The safed condition ultimately resulted when some out-of-normal limit conditions were detected by computers in the Attitude and Articulation Control Subsystem. Since entering the safed condition, Galileo has continued to function properly. As of January 26, the process of returning the spacecraft to a configuration to collect science at Venus is proceeding on schedule. The uplink memory load (known as EV-6), containing the Venus science sequence, is planned to be sent to the spacecraft on February 6 with the closest approach to Venus on February 9.

*Galileo Mission Summary**

Distance From Earth	35,422,555 kilometers (22,010,555 miles)
Distance From Venus	8,150,623 kilometers (5,064,562 miles)
One-Way Light Time	~2 minutes
Velocity Relative to the Earth	10.3 kilometers per second (23,127 miles per hour)
Velocity Relative to the Sun	35.2 kilometers per second (78,760 miles per hour)
Spacecraft Sun Angle	<1° off-Sun
Spacecraft Spin Rate	2.89 revolutions per minute
Downlink Telemetry Rate	1200 bits per second
Spin Configuration	All spin
Powered Science Instruments	Magnetometer, Heavy Ion Counter, Ultraviolet Spectrometer, Extreme Ultraviolet Spectrometer, and the Dust Detector
RTG Power Output	558 watts

**All information is current as of January 26, 1990.*



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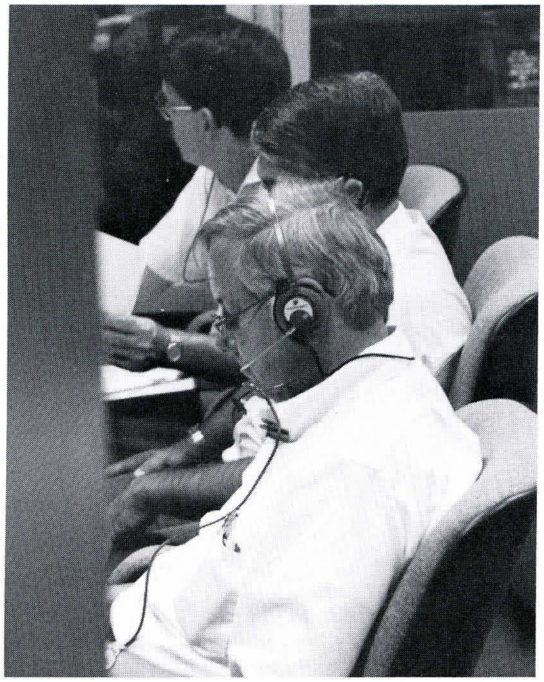

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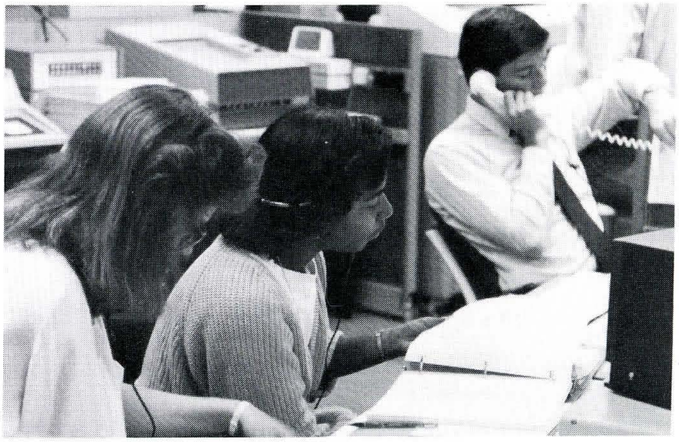
perates the spacecraft 24 hours a day, seven days a week. During n and the Venus flyby, long hours and high levels of spacecraft Flight Team's focal point is the real-time operations area, where rough a flood of data to monitor the spacecraft's performance and crew required for operations numbers in the hundreds. During e controllers were in constant communication with Johnson Kennedy Space Center at Cape Canaveral, the Inertial Upper thern California, and our own Deep Space Network around the nputer-driven display devices, hundreds of pounds of reference minute timelines, the entire Flight Team supported a flawless This same Team has transitioned from launch to cruise, continu- path to Venus—the first leg of the VEEGA trajectory.
ers in these photos are, from left: 1. Matt Landano and John Gilmore, and Bob Warzynski; 3. Dick Johnson and Jesse Smith; and Jim Yu; 5. Neil Yarnell, Neal Ausman, and Ralph Reichert; Al Davidson, Olen Adams, and Rob Kocsis; 7. Jim Yu, Pete d Ray Weaver; 8. Michele Katti, Jan Berkeley, and Curt Henry.



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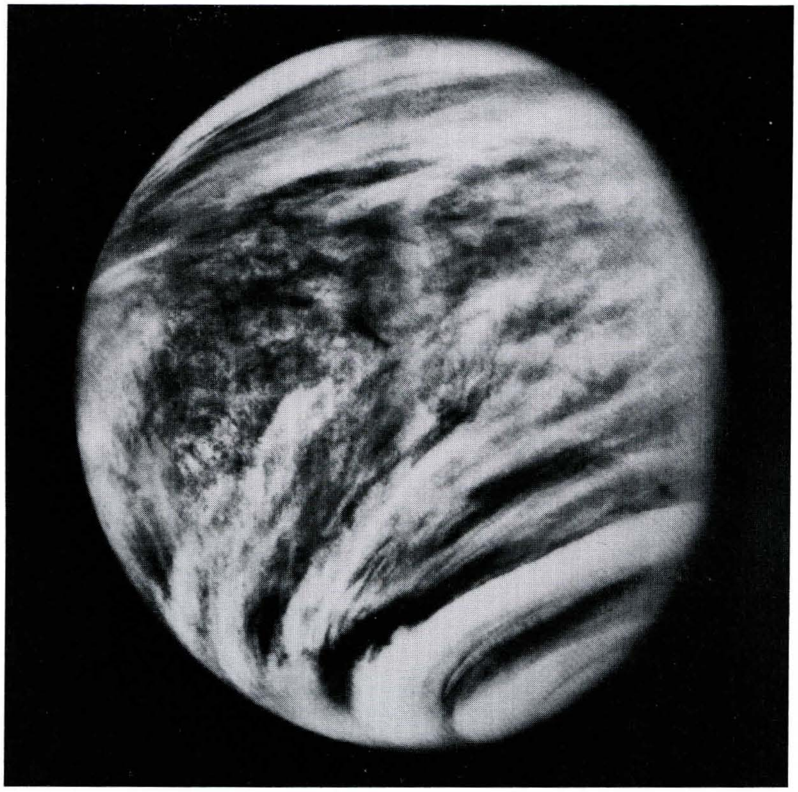
Event	Date	Time (PST)	Venus Relative: Radial Distance (mi)	(km)	Altitude (mi)	(km)	Speed (mph)	(km/s)	Sun Relative: Speed (mph)	(km/s)
Venus – 1 Day	Feb 8	09:59 PM	345,200	556,600	341,500	549,600	14,000	6.26	83,500	37.34
Venus – 12 Hours	Feb 9	09:59 AM	176,800	284,500	173,000	278,400	14,200	6.35	83,800	37.45
Venus Equator Crossing	Feb 9	08:24 PM	28,800	46,300	25,100	40,400	16,100	7.20	85,300	38.13
Venus – 1 Hour	Feb 9	08:59 PM	21,100	34,000	17,400	28,000	16,900	7.55	86,200	38.52
Venus Closest Approach	Feb 9	09:59 PM	13,800	22,200	10,000	16,100	18,300	8.20	89,400	39.97
Venus + 1 Hour	Feb 9	10:59 PM	21,100	34,000	17,400	28,000	16,900	7.55	90,400	40.42
Venus + 12 Hours	Feb 10	09:59 AM	176,800	284,500	173,000	278,400	14,200	6.35	89,200	39.86
Venus + 1 Day	Feb 10	09:59 PM	345,200	556,600	341,500	549,600	14,000	6.26	89,100	39.85

(VENUS from page 1)

instrument that helps scientists determine chemical compositions, the atmospheric structure, the nature of clouds and their energy balance, and atmospheric motions. The NIMS accomplishes all this by detecting radiation from the planet's atmosphere—either reflected solar radiation or thermal radiation from the lower cloud layers. Aiding the NIMS in these studies is the Solid-State Imaging experiment.

A total of ten Orbiter instruments will be peering, poking, and probing at Venus during the flyby, investigating lightning, global features, planetary energy emissions, temperatures at the cloud tops, magnetization in the ionosphere, auroras, and the molecular composition of clouds—the instruments will get a good workout. In fact, the Venus flyby will fine tune the Galileo Team in gathering and interpreting the data from these instruments in preparation for the hectic activity at Jupiter.



Earth-based images, like this one, show little detail in Venus' clouds, and none of the planet itself. Galileo, during its furious flyby, will unveil the terrain beneath Venus' thick atmosphere.

(PROJECT MANAGER from page 1)

sufficient energy to reach Jupiter. Subsequent Earth flybys will properly direct that energy to propel Galileo on to the Jovian giant.

As we begin to reap the rich scientific harvest that Galileo will deliver over the next seven years, we can look back, nearly 30 years ago, when plucky little Mariner II, weighing in at just 447 pounds, made history with man's first close encounter with Venus. Those of us who were involved are extremely proud, albeit somewhat nostalgically, of that accomplishment. In sharp contrast, our sophisticated Galileo spacecraft will explore Venus' environment, and the world may hardly notice in the wealth of today's technology. But, each of us on the Project looks forward to receiving these exciting Venus science results later this year and the scientific bounty of the years to come.

— Dick Spehalski

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Space Administration

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JPL 410-16-22 2/90

The Galileo Messenger

Issue 23 April 1990

From the Project Manager

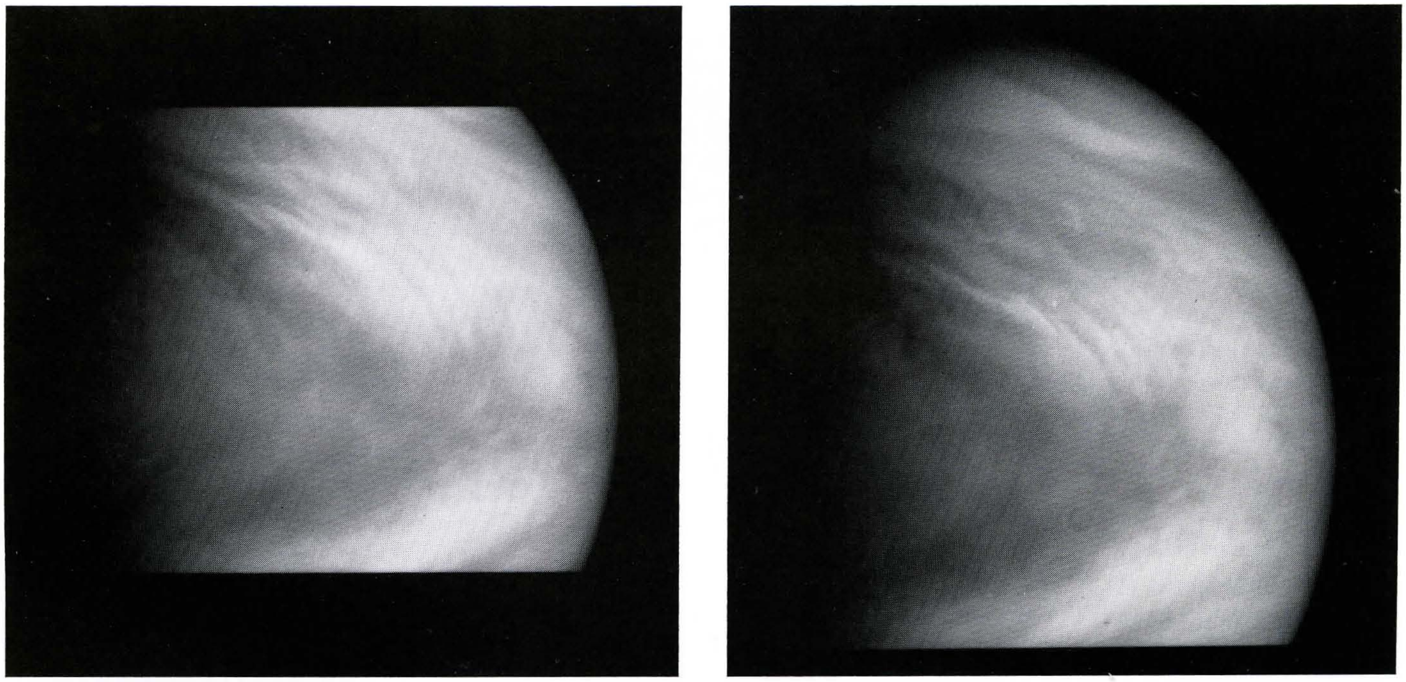
The greatest challenge in getting Galileo to Jupiter has been met. In less than four months, the Flight Team expertly conducted the inflight spacecraft checkout and characterization, including all the science instruments, and navigated Galileo to a perfect Venus gravity assist (the "V" in VEEGA) on February 9. And, Galileo flew through perihelion—the closest it will ever come to the Sun—on February 25, with no temperature problems.

We are now on a trajectory to Earth that sets up the first of our two Earth gravity assists (EGAs). The heliocentric (Sun-centered), Earth-return trajectory produced by the Venus gravity assist has already established the 9 kilometers/second Earth-relative speed needed to reach Jupiter. However, the direction of this first Earth approach (the Earth-relative velocity) is roughly perpendicular to the Earth's velocity around the Sun. The purpose of our two EGAs is to turn this Earth-relative velocity about 90 degrees so that it adds directly to the Earth's 30 kilometers/second tangential velocity around the Sun. Galileo will then be traveling 39 kilometers/second tangential to Earth's orbit. A spacecraft moving 39 kilometers/second tangential to the Earth's orbit will have its aphelion (its farthest distance from the Sun) three years later tangential to Jupiter's orbit.

The Venus flyby was excellent. Some innovative techniques were used to receive three of the 81 Venus images a few days after the flyby; all of the Venus data are stored on Galileo's tape recorder and will be transmitted to Earth this November. While Galileo is flying inside Earth's orbit (closer to the Sun than the Earth is), we must keep the high-gain antenna (HGA) furled and its tip shade pointed at the Sun so that sunlight does not strike the HGA. Consequently, the HGA is unusable. Therefore, we must wait until Galileo is approaching the Earth, when the short communication range will allow us to transmit the Venus data over one of Galileo's low-gain antennas at a standard tape recorder playback rate.

The Venus images and other science data we will receive in November will be very exciting. Galileo collected some science no other spacecraft has ever cap-

—see page 6



Venus' upper clouds show details as small as 25 miles wide, while other clouds rise from lower levels in the atmosphere. These images were taken two hours apart on February 12, when Galileo was about one million miles past Venus.

Galileo—Up To Date

The Galileo spacecraft has successfully completed its first planetary flyby—with Venus. The main objective of the flyby was to change the spacecraft's trajectory and increase its velocity by roughly 5000 miles per hour to help ensure its arrival at Jupiter in 1995. This was accomplished, making the flyby a resounding success! As an added scientific benefit, all of Galileo's Orbiter instruments collected scientific data on Venus and its environment.

Because the spacecraft can only use its low-gain antennas—the high-gain antenna is still furled to protect it against the Sun's heat—just a few images from the flyby have been returned. Matt Landano, Deputy Mission Director, explained: "We developed a special tape-recorder playback technique that allowed return of this information at a rate of 1200 bits per second (bps), whereas Galileo would normally be sending science data at no less than 7680 bps. The new technique requires about 3.6 hours to receive one image. Despite the return of just a few images, the atmospheric scientists are elated by the quality of the Near-Infrared Mapping Spectrometer and Solid-State Imaging data already received." The remainder of the Venus data will be returned around early November, when telecommunications performance using the low-gain antenna is much more favorable. For comparison, the Voyager spacecraft at Neptune had a data rate of 21,000 bps, while Galileo at Jupiter will send information at a maximum of 134,400 bps.

The only concern during the Venus flyby involved the Solid-State Imaging (SSI) Subsystem, Galileo's "camera." At 1:41 A.M. on February 10, the Flight Team noticed that the SSI was opening and closing its shutter when it should have been inactive. After carefully considering the situation and the operational alternatives, the Flight Team performed special SSI and Command Data Subsystem (CDS) memory readouts, then powered off the SSI and turned on its replacement heater to assure its health and safety. About an hour later, another CDS memory readout was undertaken and it confirmed that the CDS was no longer instructing the SSI to shutter.

Landano commended the entire Project's efforts: "From the time we recognized the anomaly until we 'fixed' it took less than 24 hours. The Flight Team analyzed and isolated the problem, assessed the implications, recreated the conditions in ground testing, identified and verified the fix, and reconfigured the spacecraft to a state compatible with continuing the stored-sequence planned imaging events on the evening of February 10. We completed these efforts with about 25 minutes to spare. All elements of the Flight Team worked very well together to get the system back 'on line.' " Due to the extraordinary efforts of the Flight Team, nearly all the imaging data expected at Venus was collected. The shuttering problem was found to be the result of a timing difference between the SSI ground-software control model and the operating flight software in the CDS, which resulted in imaging-control information being changed prior to completing the ongoing SSI control sequence.

After the extremely active Venus flyby phase, the spacecraft continued on its planned trajectory, reaching perihelion on February 25. Galileo's thermal performance was as expected, with no thermal-related anomalies or concerns reported. During the immediate post-Venus flyby period, the telemetry data rate capability dropped from 1200 bps to 40 bps and, for three weeks in March, the telemetry data rate was further reduced (for the only time) from 40 bps to 10 bps. This very low data rate was necessary to maintain acceptable data quality, in the presence of less favorable telecommunications conditions existing during this mission period. On March 28, the telemetry data rate was returned to 40 bps, thereby improving the Flight Team's visibility into the spacecraft's operations.

In mid-March, Galileo's telecommunications link operations were switched from the aft-facing low-gain antenna (LGA-2) back to the forward-facing LGA-1. The spacecraft is now executing the stored events contained in the Venus–Earth (VE-2) sequence that controls its activities from March 26 through April 23.

The spacecraft's health continues to be excellent, with system performance near predicted levels. The next major mission event is a trajectory correction maneuver (TCM4) planned for early April and mid-May 1990. The maneuver is crucial in shaping Galileo's trajectory for the first Earth flyby on December 8, 1990. ✯

*Galileo Mission Summary**

Distance From the Earth	121,829,620 kilometers (75,701,420 miles)
Distance From Venus	20,716,910 kilometers (12,872,890 miles)
One-Way Light Time	6 minutes, 44 seconds
Velocity Relative to the Earth	24.46 kilometers per second (54,720 miles per hour)
Velocity Relative to the Sun	36.95 kilometers per second (82,650 miles per hour)
Spacecraft–Sun Angle	2.3° off-Sun
Spacecraft Spin Rate	3.15 revolutions per minute
Downlink Telemetry Rate	40 bits per second
Spin Configuration	Cruise Mode—dual-spin
Powered Science Instruments	Ultraviolet Spectrometer, Extreme Ultraviolet Spectrometer, Magnetometer, Dust Detector, and Heavy Ion Counter
RTG Power Output	554 watts

**All information is current as of March 30, 1990.*

Networking Out of This World

Four spacecraft fly to the cold reaches of interstellar space, dozens orbit in a frantic pace around the Earth, others fly to and orbit the planets, and Galileo continues its roller coaster ride through the solar system. What do all these missions have in common? The only ear that can hear all their voices belongs to NASA's Deep Space Network (DSN).

Spanning the globe, from Goldstone, California, to Madrid, Spain, to Canberra, Australia, three Deep Space Communications Complexes (DSCCs) listen in on all this space chatter and transmit it on to the scientists and engineers working in ground support and on the project teams for the various spacecraft. Each DSCC has four very large antennas (one 26 meters, two 34 meters, and one 70 meters in diameter) that can pick up faint signals from space. Each of these antennas has a specialized function. For example, the 70-meter antennas can retrieve very faint signals, while the 26-meter antennas are best for tracking launches or Earth-orbiting satellites since these smaller antennas can move quickly across the sky, keeping pace with the satellites. The 26-meter antennas will be used during Galileo's Earth encounters.

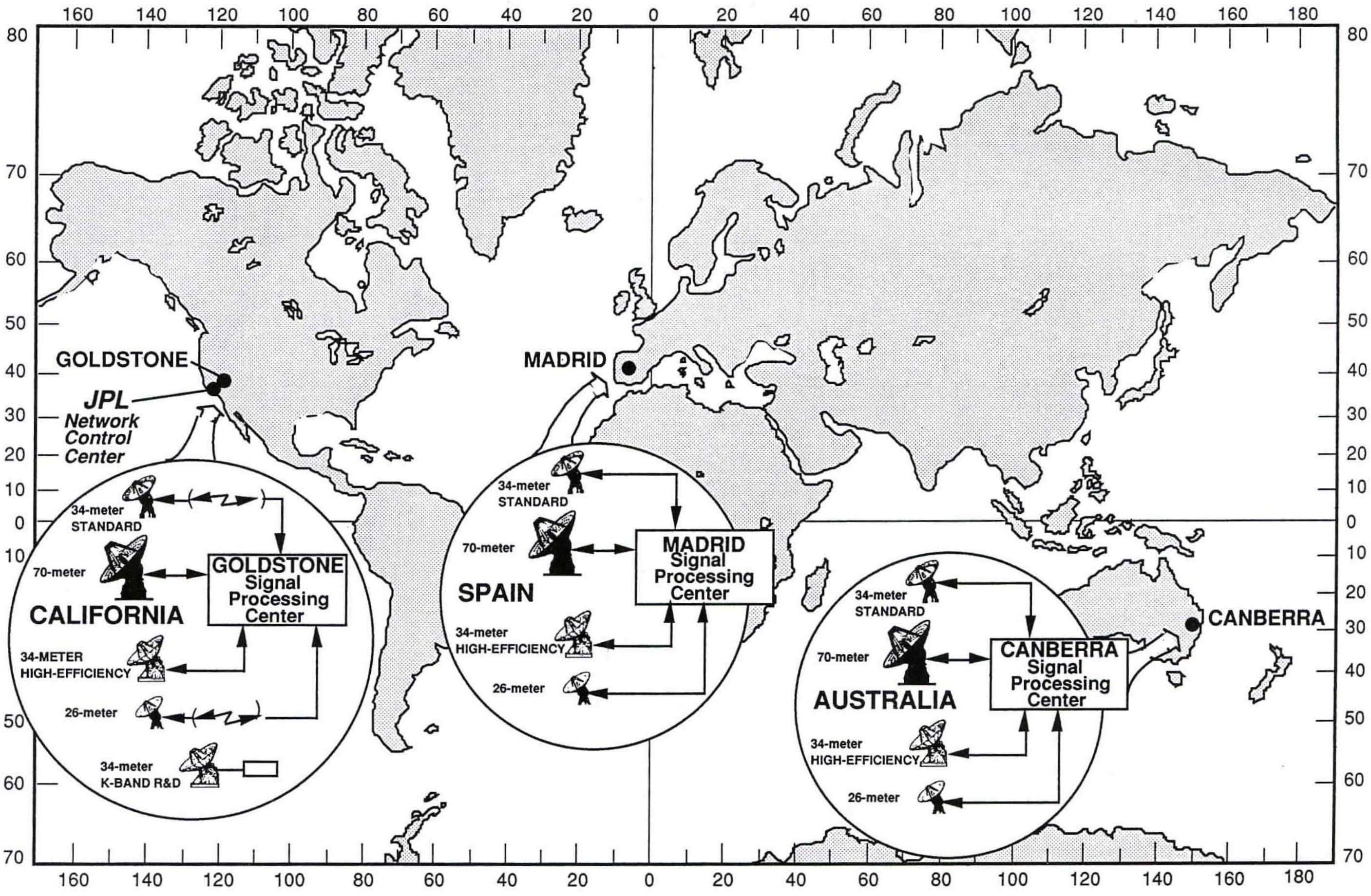
Until the Venus flyby, the DSN was devoting about 30% of its time to the Galileo mission. This commitment will decrease during the quiescent cruise time, will increase slightly during the two Earth encounters, and will increase dramatically as Galileo approaches Jupiter and enters the satellite tour phase of the mission.

Although the DSN devotes some time each week to maintaining the DSCCs, unique dilemmas occur now and then. For instance, just after Galileo's launch, an elevation bearing under Madrid's 70-meter antenna failed and put the antenna out of service. According to Douglas Mudgway, Tracking and Data System Manager for Galileo, "This occurred suddenly and without warning. It required a major effort over several weeks to repair because of the enormous loads on the bearings—each bearing carries half of the 4,200,000-pound antenna load." The cause of the failure at this point is unknown, but the DSN engineers are continuing to analyze the problem to prevent its recurrence.

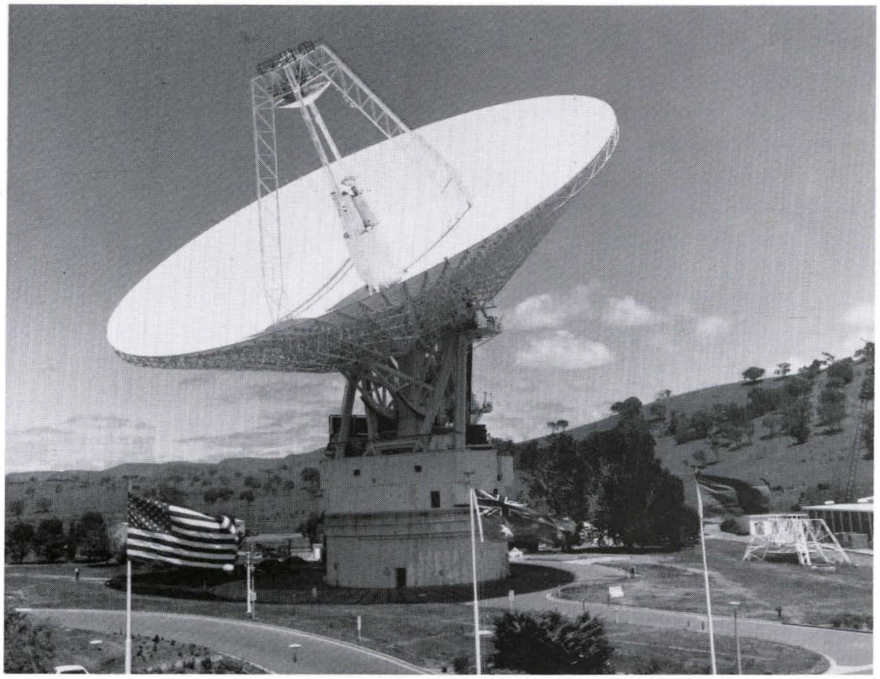
Another interesting situation developed during the Venus encounter, when high winds in the California desert necessitated shutting down the Goldstone site. The Canberra Complex had to come on about four hours early to support Galileo's needs.

Galileo poses some unique challenges to the capabilities of

—see page 4



The DSN's antenna complexes, located around the globe, can always keep one antenna pointed toward Galileo.



In Australia, Canberra's 70-meter antenna picks up Galileo's faint signals from space.

(NETWORKING from page 3)

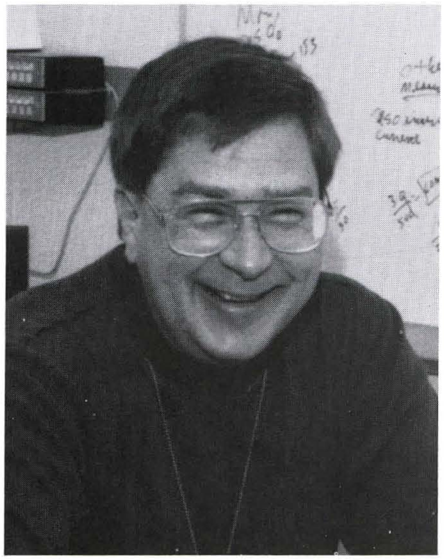
the DSN. Because of thermal considerations, Galileo's high-gain antenna (HGA) must be shielded behind its sun shades until the spacecraft is at a safe distance from the heat of the Sun. As a result, only the low-gain antennas can be used, and even they cannot be pointed ideally toward the Earth. Until the HGA can be used in May 1991, DSN support is greatly complicated, but has been outstanding in all respects, according to Neal Ausman, Galileo Mission Director.

In a recent tour of the DSN sites by Galileo Project management, Mudgway noticed that interest in the Project was high, not only at the DSN sites, but also throughout the local community. "The public is interested in the challenges of the Galileo mission," Mudgway noted. "People find it difficult to imagine that a [planetary] spacecraft so soon after launch is down to a data rate of 40 or 10 bits per second (bps) on the 70-meter antennas. This is very unique. Normally you would expect a 1200-bps rate or higher."

When the spacecraft reaches Jupiter, it will be at its maximum distance from the Earth and the DSN's antennas, unavoidably degrading the performance. To compensate, several plans of action are possible. First, the DSN can "combine" the data-gathering capacities of all the antennas at one site to enhance their function. Second, the DSN plans to develop new coding and decoding schemes by May 1991, which will allow more efficient reception of the data from Galileo. Finally, the Network will continue to evaluate several alternatives to improve antenna performance, including the use of other non-DSN facilities, although, according to Mudgway, "The DSN is almost at its theoretical limits for deep-space telecommunications like this." ✯

Meet the Team Leader in the OET

For those not intimately associated with the Galileo Project, it might seem as if the spacecraft flies its complex trajectory effortlessly, collecting images and data as it heads toward Jupiter and its place in history. However, Galileo is only a sophisticated machine that follows the commands of the Galileo Flight Team. The Orbiter Engineering Team (OET) creates these commands and oversees the engineering operations of the spacecraft, making sure it remains safe, and using Galileo's resources wisely. This Team is led by Team Chief Robert Kocsis.



Rob Kocsis

In overseeing the OET, Rob makes sure the spacecraft is kept healthy so that the mission objectives can be realized and the science teams on the Project can satisfy their objectives. He and his Team maintain the health of the spacecraft by monitoring the engineering data (the temperatures, pressures, voltages, and currents), calibrating the equipment, ensuring safe operation within the current capabilities, and watching over the lifetime limits of each piece of hardware. By running tests and looking for any changes over time or deviations from expected values, the OET can determine trends and identify Galileo's unique characteristics. As the mission progresses, the OET learns to assess

Galileo's capabilities and develops an understanding of its responses.

Nearly 100 people comprise the OET, and Rob is supported by three deputies: Arden Accord, in charge of real-time operations, Pete Kobele, leading the analysis group, and Dave Durham, supervising the uplink design. The efforts in each group vary with time.

As the mission has progressed, Rob observed, "We have used the real-time commands more than anticipated. We didn't account for the amount of effort required and some of the surprises Galileo had in store. Oddly, we've had a hard time finding stars, mainly due to the VEEGA trajectory and thermally based pointing constraints on the spacecraft. We have an expectation of how the stars should be perceived by the spacecraft, but how it really works can be something entirely different."

In his work, Rob interfaces with the Galileo Project, reviews technical issues and strategies, works with other teams comprising the Flight Team, and coordinates the three OET areas, monitoring the Team's overall efforts.

While enjoying the technical challenges in his work, he is most fascinated by the people he interfaces with. A true fan of Galileo, his pride is echoed throughout his Team, "This marvelous spacecraft is incredibly complex and works extremely well. However, even though you think you understand it, you may not. You have to be very careful and constantly keep learning. But, we have never done so much with any other spacecraft so soon after launch."

Rob came to JPL in October 1966 from Brown University in Providence, Rhode Island, with a bachelor's degree in aeronautical and astronautical engineering, specializing in fluid mechanics and thermodynamics. He started in Division 35, where he designed mechanical devices for Mariners '69 and '71. During that time he finished his thesis and received his master's degree in 1968. He then moved on to systems engineering and fault protection for the Viking mission, working at the Cape for both Viking launches, and performing real-time operations through the landings on Mars. Later, he supervised the advanced designs group in Division 35.

When he's not leading the OET, Rob enjoys hiking in Griffith Park with the Sierra Club and biking throughout Southern California, photographing people and nature. He and his wife, Patricia, have two sons, Jonathan at U.C. Santa Cruz and David at New York State, who with their father enjoy ice hockey and basketball. On a warm summer's night, you might catch Rob and Patricia listening to Mozart, Bach, or Al Jarreau at the Hollywood Bowl, still keeping an eye on the spacecraft. ✯

The caption for the image of Venus on page 4 of issue 22 of The Galileo Messenger *erroneously read: "Earth-based images, like this one, show little detail in Venus' clouds, ..." Actually, the image was taken by the Mariner 10 spacecraft, and in fact showed a good deal of detail. My apologies.*

—Editor

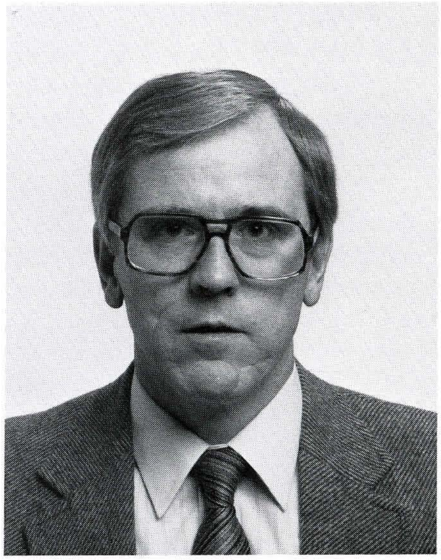
Editor's Note

The new Galileo Project Manager is William J. O'Neil, following Richard Spehalski's move to the Space Infrared Telescope Facility project.

Bill has been involved with the Galileo Project since its inception. Coming from a strong background in mission design and navigation, Bill had been Galileo's Science and Mission Design (S&MD) Office Manager since 1980. During the development phase, the S&MD Office was responsible for mission design, all interfaces with the scientists, and development of the Orbiter's science instruments.

Bill studied aeronautical engineering, receiving a bachelor's degree from Purdue and a master's degree from the University of Southern California. Since joining JPL in 1963, he has worked on the moon lander Surveyor, the Mariner Mars 1971 orbiter, and the Viking Mars landers and orbiters. He was Manager of the Mission Design Section before joining the Galileo Project.

Bill and his wife Diane live in Sierra Madre and have three adult children. Last year was a banner year for the O'Neils: in addition to the launch, all three of their children moved back to Sierra Madre, the oldest and his wife bringing Bill and Diane's first granddaughter. Although they enjoy traveling and downhill skiing, on some weekends Bill can be found looking after their real estate investments—painting and fixing plumbing in their "mom and pop" apartments. ✯



William J. O'Neil

For the Flight Team

As Galileo was being deployed from the Space Shuttle Atlantis, Commander Don Williams said, ". . . Galileo is on its way to another world. It is in the hands of the best flight controllers in this world."

His comments were very flattering and in my opinion 100% correct. The Galileo Flight Team has done an absolutely outstanding job. In slightly less than four months, the Flight Team has participated in a flawless launch and deployment, a reconfiguration of the spacecraft from launch to cruise mode, and a characterization of the spacecraft, including its science instruments. The members of the Flight Team promptly diagnosed the cause for Galileo's entry into fault protection, and then carefully and methodically reconfigured the spacecraft to a state compatible with that required at the start of EV-6.

During the Venus encounter sequence, the Flight Team correctly diagnosed a sequencing problem in a matter of hours, allowing the Solid-State Imaging instrument to be turned back on and to complete the balance of its planned data-gathering sequence. The Team also generated and transmitted several last-minute commands thermally controlling the Near-Infrared Mapping Spectrometer to assure it was able to acquire meaningful data from Venus. All the while, the Team was dealing with an unexpectedly difficult star selection process required to keep the spacecraft properly oriented.

The Galileo Flight Team has responded professionally to every challenge and has willingly devoted hours of overtime to achieve a spectacular start to the mission. I am proud to be a part of the Galileo Flight Team. It is composed of exceptionally talented, completely dedicated people—you are the best flight controllers in the world. ✯

—Neal E. Ausman, Jr.
Galileo Mission Director

So Long . . .

As of February 26, command of the Galileo Project was turned over to Bill O'Neil and I moved on to be the Project Manager of the Space Infrared Telescope Facility.

My memories of twelve years on the Galileo Project are varied, just as I am sure are yours. We have endured times that were challenging, as well as threatening, and we have enjoyed success. Your performance in the years before launch, as well as the months of intense activity culminating in an outstanding Venus encounter, has been superlative. We all are elated and take pride in the successes we have shared. But, the real excitement is yet to come.

Godspeed!

—R. J. Spehalski

(PROJECT MANAGER from page 1)

tured. All of the science instruments performed very well at Venus. A subtle flaw in our sequencing of Galileo's Command and Data Subsystem caused the camera to shutter many more times than we intended. The Flight Team quickly resolved the problem and there was no damage to the camera or loss of data; the spacecraft and the mission were never in jeopardy.

Construction is nearing completion on a full-size replica of Galileo, using the Development Test Model and spare parts, in JPL's Spacecraft Assembly Facility, Building 179. This replica will allow us all to appreciate the full-scale details of Galileo's actual mission configuration and will let us show a magnificent replica of Galileo to others.

We are now preparing our observing plans for the first Earth–Moon encounter in December 1990 and for the Asteroid Gaspra encounter in October 1991. Following our Gaspra encounter, and in concert with our final Jupiter tour design, we will decide in June 1992 whether to also perform an encounter with Asteroid Ida in August 1993.

The Venus flyby was a great achievement for all of us in quickly understanding the spacecraft's subtleties and dealing with surprises. I'm amazed and impressed by what we have accomplished in these first six months. It is my honor to be associated with such an outstanding team and with the most exciting planetary mission for the balance of this century. ✯

—Bill O'Neil

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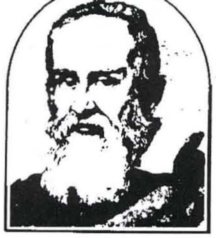


The Galileo Messenger

Issue 24 July 1990

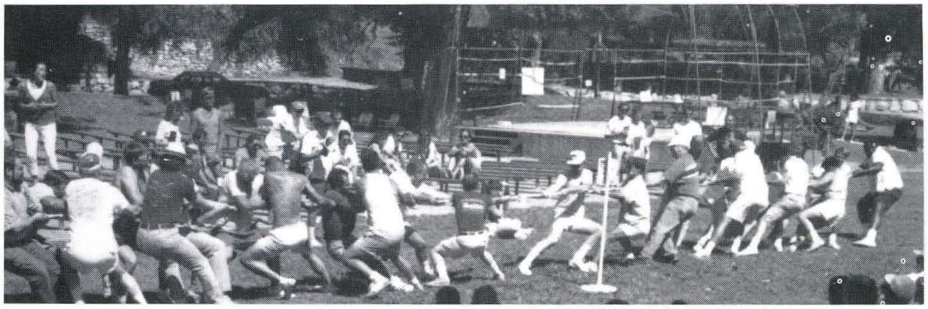
From the Project Manager

Galileo continues to perform beautifully.

In April and May we executed the fourth Trajectory Correction Maneuver (TCM). TCM4 is of very special significance because it provided the velocity change (the ΔV) necessary to "patch" Galileo's post-Venus, heliocentric (Sun-centered) orbit to the required heliocentric Earth-return orbit. For some months after Roger Diehl discovered the Venus–Earth–Earth Gravity Assist (VEEGA) trajectory in July 1986, it was believed that Galileo could only be launched onto the desired VEEGA path in November 1989. The continuing research of Lou D'Amario and Dennis Byrnes revealed that performing a ΔV maneuver between Venus and the first Earth flyby would allow Galileo's launch throughout most of October 1989 as well. Thus, the actual Galileo launch on October 18, 1989 was enabled by building this "deterministic" TCM4 into the trajectory's design.

TCM4 was performed in two parts. Part A consisted of four days, April 9 through 12, of pulsing the lateral thrusters throughout each day shift to produce 24 meters/second. Part B consisted of two days, May 11 and 12, of pulsing, which produced 11 meters/second. The total ΔV of 35 meters/second was the largest TCM Galileo must perform to get to Jupiter. The overall accuracy of TCM4 was well within our required tolerances. The remaining maneuvers before this December's Earth flyby are very small (approximately 1 meter/second) and

—See page 3



A picnic celebrating Galileo's successful launch helped the whole Project pull together . . . well, most of the time. (More picnic capers appear on page 6.)

Galileo: Up to Date

The spacecraft continues to operate well, with performance levels near the predicted values.

Although not as crucial as earlier in the mission, it is still important to keep Galileo safe from the Sun's heat, with the spacecraft's body sheltered behind the protection of its sunshades. If sunlight were to shine on and heat some of the elements, they could be damaged. As a consequence of its trajectory, Galileo must periodically turn several degrees to keep pointed within safe angles away from the Sun. Each of these turn activities or SITURNs requires significant effort from the Flight Team and coverage from the Deep Space Network. Since Galileo is now more than one astronomical unit (93,000,000 miles = 1 AU) from the Sun, fewer, but larger, SITURNs are being used. The largest SITURN so far, about 13 degrees, was performed on June 14; Galileo performed as expected and without incident.

SITURNs and other activities are controlled by the spacecraft's computer programs. These programs are transmitted to Galileo every few months or so and cover all planned activities in a given time period. The third sequence-memory-program load since Venus encounter (VE-3) was successfully transmitted and executed by Galileo from April 23 through June 11. Each sequence is usually loaded onto the spacecraft only a few days before its active period begins. The VE-5 sequence, successfully transmitted and received by the spacecraft on June 8, controls spacecraft activities from June 11 through October 22. This is the longest stored sequence yet received by Galileo.

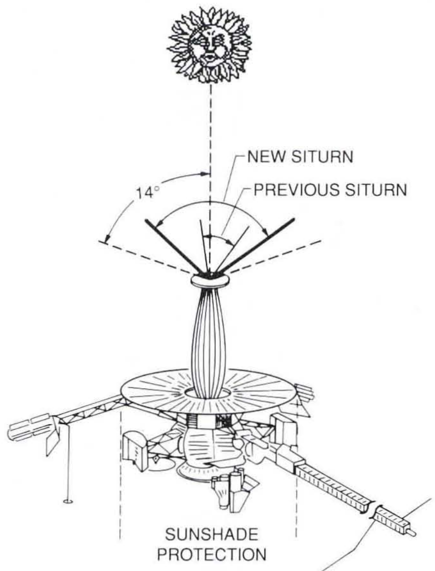
Sequence memory loads for other major events, such as a Trajectory Correction Maneuver (TCM), are sent separately to the spacecraft. In the case of TCM4A, the load was sent in four sections, from April 8 through 11. During one of the burn segments, a thruster temperature measurement nearly instantaneously went from the expected level to a saturated level. This behavior is likely indicative of a transducer interface failure. Since these transducers were added late in the program and installed on the thrusters using an unqualified technique accepted by the Project on a "best-effort" basis, the failure is not seen as a threat to the thrusters. Additionally, this failure can be partially compensated for by other temperature sensors in the retropropulsion module cluster. TCM4A imparted very nearly the required 24.8 meters/second increment in

velocity with a slight underburn of about 0.48 meters/second. Despite small pointing-error changes and the apparent loss of the thruster temperature transducer, Galileo performed well throughout the four-day, 24-segment maneuver. This was the first time that the L-thrusters exclusively had been used for a large burn. The number of L-thruster pulses in TCM4A was more than 10 times that used to date for the entire mission. As a consequence of some of the pointing errors observed in TCM4A, changes were made to the TCM4B maneuver design to reduce and correct for any pointing error.

On May 11 and 12, TCM4B imparted an additional increment in velocity of 11.3 meters/second using the thrusters. Galileo performed very well throughout the two-day, 10-segment maneuver, and the largest pointing error observed was about half that seen in TCM4A. The TCM4B maneuver imparted nearly the required increment in velocity with some small underburn. An investigation is in process to understand the reasons for this underburn.

Investigative efforts are continuing into the unexpected readings observed on the AC/DC bus imbalance measurements. Both measurements began exhibiting unexpected behavior in December 1989. A Tiger Team, brought together to lead the investigation, has not yet found the cause of the unexpected readings. The observed bus imbalances do not present a serious threat to Galileo's health and safety. All other power and other subsystem-related telemetry indicates that all activities are near our expected performance.

Another unexpected incident at the end of April involved a recurrence of a despun Command Data Subsystem (CDS), critical-controller, power-on reset (POR) telemetry event that was first observed in late February. Both times, commands were sent to Galileo to "clear" the telemetry indication. Successful resetting of the telemetry indicator provided confidence in the CDS' integrity and that the POR indication was caused by a "transient" and not a hard failure.



At Galileo's current distance of over 1 AU from the Sun, larger, less frequent SITURNs can safely be used. Previous SITURNs were only about half as large.

Investigative efforts revealed that both events were similar and did not indicate the presence of a real POR event. Circuit analysis and testing showed the likely cause of these two events may be due to electrical noise coupling between the adjacent 2.4-kilohertz power interfaces and the CDS POR signal, both of which traverse the spin-bearing assembly via slip rings. Further detailed testing and analysis are in process.

In addition to the day-to-day operation of the spacecraft, the Project must look ahead to prepare for the hectic activity once Galileo arrives at Jupiter. Currently, the spacecraft transmits information back to the Deep Space Network's (DSN's) antennas at the rate of 40 bits per second. That rate will increase to 134,000 bits per second at Jupiter. In anticipation, the Galileo Project and the DSN have been planning how best to support the mission at Jupiter with the DSN's capabilities and other commitments. The DSN has recently conducted Mission Readiness Tests at all three 34-meter high-efficiency antenna sites, thus qualifying those stations for supporting Galileo as early as April 1991, when the High-Gain Antenna can be unfurled and available for use. A Galileo Array Study Team is looking at DSN support of the important science occurring at closest approach to the moon Io, just before Jupiter Orbit Insertion. The Project requires a 99% confidence that Io data will be captured.

Although Galileo is not scheduled to study an asteroid until October 1991, the spacecraft did have an opportunity to glance at a comet. Commands were sent on May 12 to reconfigure the Extreme Ultraviolet (EUV) instrument in an attempt to capture unique scientific observations, including looking for ionized oxygen, in the coma of the Comet Austin. At this time, however, no positive detection of oxygen ions can be reported.

Another aspect of the Project's long-term planning centers on supporting the Probe upon its arrival at Jupiter. The second

Galileo Mission Summary*

Distance from the Earth	154,889,000 kilometers (96,243,000 miles)
Distance from Venus	100,871,000 kilometers (62,678,000 miles)
Distance from Jupiter	932,353,000 kilometers (579,337,000 miles)
One-Way Light Time	8 minutes, 37 seconds
Velocity Relative to the Earth	20.25 kilometers per second (45,350 miles per hour, mph)
Velocity Relative to the Sun	25.39 kilometers per second (56,800 mph)
Spacecraft–Sun Angle	10° off Sun
Spacecraft Spin Rate	3.15 revolutions per minute
Downlink Telemetry Rate	40 bits per second (low rate)
Spin Configuration	Dual spin—cruise mode
Powered Science Instruments	Ultraviolet Spectrometer, Heavy Ion Counter, Extreme Ultraviolet Spectrometer, Dust Detector, and Magnetometer
RTG Power Output	552 watts

**All information is current as of June 14, 1990.*

Probe Flight Operations Equipment (PFOE) station was recently installed in the Mission Support Area. PFOEs will enable the Probe's Engineering and Science Teams to process information from the Probe.

— Matt Landano

(PROJECT MANAGER from page 1)

are scheduled for July 17, October 9, and November 13 and 28.

At 8:17 A.M. PDT on May 28, Galileo's distance from the Earth stopped increasing and began decreasing; the distance will now steadily decrease until Galileo's closest approach to Earth on December 8, 1990. Since May 11, Galileo has been flying outside of the Earth's orbit and will reach its first aphelion (farthest point from the Sun) on August 23.

Galileo is regularly collecting fields and particles data as it flies through the interplanetary medium. Engineering functions such as "Sun-pointing" attitude updates, propellant line flushing, and general housekeeping continue without incident. A sequence load (VE-5), uplinked to the spacecraft on June 8, will control the spacecraft's activities until October 22. Because Galileo will remain well outside Earth's orbit (farther from the Sun than the Earth is) during this period, greater off-Sun angles are tolerable and, therefore, only five Sun-pointing attitude maneuvers are programmed.

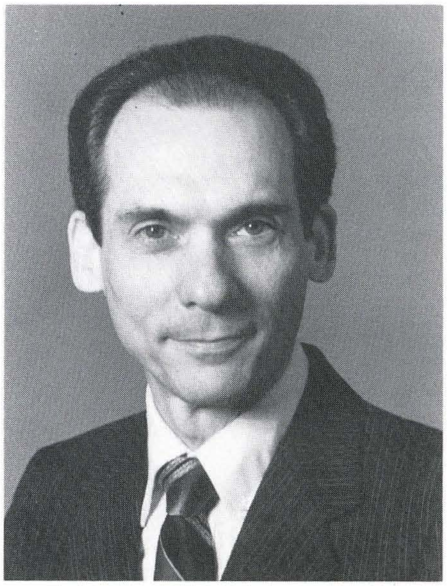
We are now developing detailed observation plans for the Earth and Moon at the upcoming encounter. These plans will be the central topic of our Project Science Group meeting on August 15 and 16. We are also fully engaged in our Phase 2 Mission Operations System Design Verification for operations at Jupiter. The results of that verification will be presented to the Galileo Review Board early in November.

Our full-size replica of Galileo in full Jupiter flight configuration is now complete and on display in the Building 179 Spacecraft Assembly Facility (SAF). It is really stunning. You can view it anytime from the SAF Viewing Gallery.

—Bill O'Neil

Flying Into the Ions' Den

The Galileo Project is full of stories of people overcoming immense challenges. Change the launch vehicle? No problem, we'll redesign the hardware and use gravity assists from the planets. Postpone launch for ~~2~~, ~~4~~, 7 years? We'll just redesign the mission—again and again. Discover a year before launch that space is nastier than imagined? We'll design, build, and test a unique instrument to monitor the gremlins. Of course, that instrument will also be able to collect some pretty dazzling science, too.



Ed Stone

The monitor is the Heavy Ion Counter (HIC) and the gremlins are heavy ions, which can cause random changes in a spacecraft's electronics. The HIC was conceived in 1984, to answer concerns the Project had about single-event upsets (SEUs) that were then occurring on Earth-orbiting satellites. An SEU is a random, stored, computer bit haphazardly changing its value from a "0" to a "1" or vice versa. Such "bit flips" on a spacecraft could trigger a chain reaction of erroneous commands with disastrous results. An SEU is caused by a heavy ion (such as the nucleus of an oxygen atom) penetrating the delicate electronics in a spacecraft and causing the bit to flip. Heavy ions of oxygen and sulphur are extremely common in Jupiter's environment. The HIC was created to measure and monitor these heavy ions.

When SEUs became known in 1984, Galileo was to be shipped to Cape Canaveral in December 1985. That left little more than a year for Team Leader Ed Stone and Tom Garrard of the California Institute of Technology, along with Neil Gehrels and Don Stillwell of the Goddard Space Flight Center, to deliver an instrument that had never before been contemplated. Fortunately, Ed Stone was (and still is) also the Principal Investigator for the Cosmic Ray Science Team (CRS) on the Voyager Project. He and his colleagues, including the late Al Schardt of Goddard, saw the possibility of reworking the CRS test model into a new Galileo instrument. Ed related, "We repackaged the instrument (which had been in storage), updated the electronics for Galileo's requirements (with assistance from JPL's Don Johnson), and redesigned the sensor system to optimize the detection of heavy ions."

Concurrently, the Project was systematically modifying the rest of the spacecraft and its electronics to be resistant to the penetration of heavy ions. Ironically, because the HIC uses older components, it is one of the most SEU-resistant instruments on board Galileo. (The newer, high-tech components in use since the mid-1980s are more delicate than Voyager's mid-1970s' parts.)

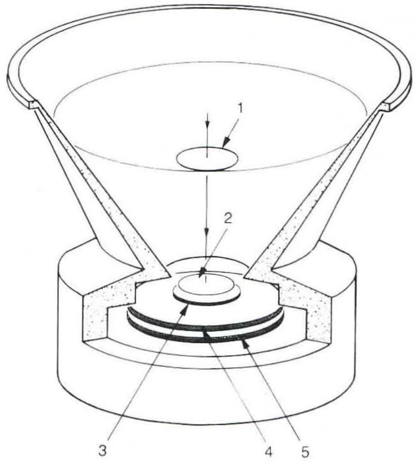
SEUs are of great concern specifically to Galileo since the Jovian environment is one of the richest in heavy ions. On Jupiter's moon Io, volcanoes constantly erupt, spewing forth oxygen and sulphur, which then settle on Io's surface. The interaction of Io with Jupiter's magnetosphere strips the oxygen and sulphur from Io's surface at the rate of a ton per second, tearing these particles from Io's gravitational influence and expelling them into Jupiter's magnetosphere. These particles become electrically charged and many diffuse outward to 1.5 to 3.6 million kilometers from Jupiter, where they are accelerated by an interaction with the massive Jovian magnetic field. Ed explains, "About 0.2% of the original particles, now highly energized,

diffuse back toward Jupiter. The ions may have left Io at one-thousandth the speed of light. By the time they return to about 700,000 kilometers from the planet (near Europa's orbit), these ions have accelerated to one-tenth the speed of light (about 30,000 kilometers/second)!" Some of these ions travel along Jupiter's magnetic field lines and spiral into the planet's polar region. In fact, these heavy ions falling into Jupiter's atmosphere may be the single largest contributor to Jupiter's auroras.

Heavy ions are also flung off from the Sun during solar flares. Just after launch, four very large solar flare events occurred. The HIC was turned on for 20 days and detected a great many heavy-ion impacts. However, since no SEUs have happened on Galileo, the radiation-hardening of the spacecraft's components is apparently working well. The heavy ions observed by the HIC during these flare events are analyzed to determine the composition of the Sun. This analysis is a continuation of similar studies from Voyager's CRS. Current indications are that the ejecta from these very large flares are like those observed by Voyager in smaller solar flares. This result was presented to the American Geophysical Union in Baltimore, Maryland, on June 1 and is the first "publication" of scientific results from Galileo.

The HIC and the Extreme Ultraviolet Spectrometer share a communications link on Galileo, and thus must divide observing time between themselves. The HIC will be turned on more frequently once the High-Gain Antenna is unfurled in May 1991.

The HIC actually detects heavy ions using five single-crystal silicon wafers, ranging in thickness from 30 to 2000 micrometers (0.001 to 0.08 inches). Each of these wafers has gold and aluminum electrodes on its surface, arranged in arrays called telescopes (as illustrated). A fast-moving ion enters one of two telescopes. It may, for example, pass through the first and second silicon wafers and stop in the third, ionizing the silicon through which it travels. The resulting



Ions enter the HIC's telescope and pass through up to five silicon wafers (numbered discs). The signals these ions evoke are translated by the charge-sensitive preamplifiers, amplifiers, analog-to-digital convertors, and digital circuitry that comprise the HIC's electronics.

ionizations are collected as electrical signals that are amplified and then analyzed to determine the particle's charge and speed. A sulfur ion, which has an electrical charge of 16, would create a signal four times as large as would an oxygen ion (with a charge of 8) moving at the same velocity. (In other words, the signal is proportional to the square of the ion's charge.) If there is no signal in the last silicon wafer, the heavy ion stopped in the preceding wafers and all its energy has been recorded.

With two telescopes, the HIC can measure heavy ions with energies as low as 6 million and, incrementally, as high as 200 million electron volts (MeV) per nucleon (that would be 3200 MeV for sulphur's charge of 16). This range includes all atomic substances between carbon and nickel, including, of course, oxygen and sulphur.

"Galileo's HIC can detect ions with energies up to about half the speed of light, nearly three times the capabilities of Voyager instruments," Ed Stone enthusiastically notes. "Its telescope is five times the size of Voyager's. It will especially watch for changes over time, since we will be residing in one environment for so long. This is a great opportunity."

A Flawless Mission by Design

Since the Galileo Project has been around for over a dozen years, one would expect the Mission Design Team, which oversees the long-range planning for the Galileo Project, to be staffed by grizzled veterans who have been with the Project since the start. Well, there's not much grizzle to be seen. The Mission Design Team (MDT) members are some of the youngest on the Project.

Armed with a wide breadth of knowledge about the Project and its requirements and constraints, boundless enthusiasm, and the knowledge that they won't be retiring before the end of the mission, the MDT members synthesize the Project's goals and turn them into schedules, plans, software, and guidelines. Under the lead of Chief Jan Ludwinski, the MDT comprises four smaller groups: Mission Planning, Orbit Plan Design and Integration, Guidelines and Constraints, and Software. "Our knowledge must be broad," Jan says. "We have to know a little bit about everything on the spacecraft and ground support and how it fits together."

Looking months to years to the future, the Mission Planning Group (Bob Molloy and John Kehrbaum) is responsible for the long-range Mission Plan, which describes Galileo's expected trajectory, data rate, Deep Space Network coverage, the science teams' needs, engineering, and navigation—all at a high level. At this point in the planning stage, the smaller details have yet to be worked out. However, it is during the development of the Mission Plan that this Group can identify potential problems and institute new guidelines and constraints.

The Orbit Plan Design and Integration Group (OPD) develops initial Cruise and Orbit Plans; detailing events minute by minute, and generating a computer file that is the ancestor of what will be sent to the spacecraft. This Cruise Plan is then passed to the

Members of the Mission Design Team continue to keep a close watch over Galileo's consumable resources. Surrounding this recently completed replica of Galileo are, from left, Team Chief Jan Ludwinski, Bob Molloy, Bruce McLaughlin, Jo Pitesky, Steve Licata, Shirley Whittington, Lisa Borel, Eilene Theilig, Jennifer Cruz, and Johnie Driver (John Kehrbaum is not pictured).

Sequence Team, which will add further details. Lisa Borel, Johnie Driver, and Bruce McLaughlin, under the lead of Eilene Theilig, pore over the science requests to include all that are possible in a given Plan. The Group also works with other elements of the Flight Team to develop a Cruise Plan, bringing the whole Plan together just 8 to 15 weeks before the targeted event occurs. The Plan details minute-by-minute sequencing of science observations and DSN coverage. Currently, the Team is working on the VE-11 Cruise Plan, which begins the sequence of details surrounding Galileo's flyby of the Earth.

The Guidelines and Constraints Group cross-checks the OPD and Mission Planning Groups' adherence to constraints and is the custodian of the Mission Plan Guidelines and Constraints. Within this Group, Steve Licata can be found, defining activities at a high level, compiling general and detailed guidelines and constraints, and allocating resources. Steve also studies how the scientists' requests for certain observations by Galileo will impact the consumables on board the spacecraft. What is a consumable? Anything the spacecraft cannot replace, but continues to utilize: operating the tape recorder, opening the thruster valves, spinning the gyros, and using propellant.

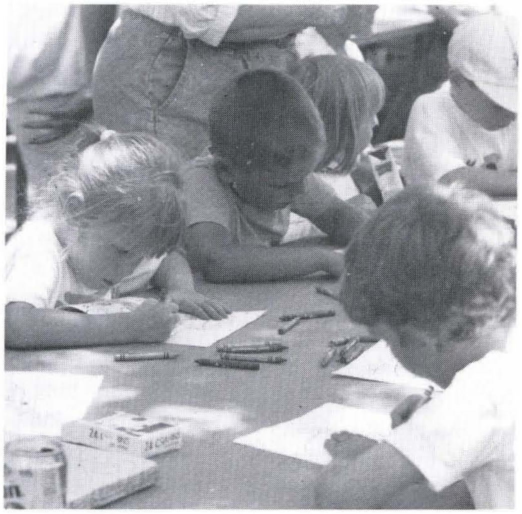
The Software Group is primarily responsible for developing the MDCHECK program. This program will check constraints at the "LINK" level and record the use of consumables. Cognizant Engineer Jennifer Cruz and Algorithm Engineer Jo Pitesky will deliver MDCHECK this month. That software includes the first adaptation of the Space Flight Operations Center's uplink tools for Galileo. As the mission develops, this Group will continue to update MDCHECK, delivering another version in 1993. The MDT was also the developer of the TIMELINE program, for which Johnie Driver is the Cognizant Engineer.

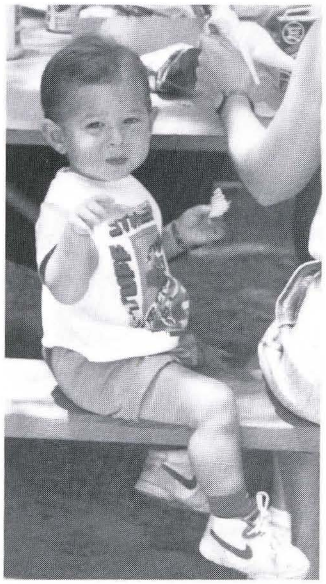
These groups do not have hard and fast boundaries. As Jan points out, "There is always some overlap between the groups and, with the tremendous depth of cross-training on the Team, we can help each other out to meet our deadlines." The whole Team's administrative needs are met by Shirley Whittington.

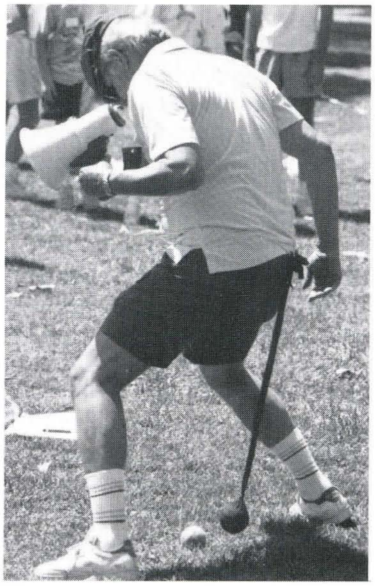
The leader of this Team has always enjoyed astronomy and planetary science. After graduating with a bachelor's degree in astrophysics from Michigan State University in 1980, Jan Ludwinski went to Hughes Aircraft Company to work as a technical writer. Rockwell International beckoned in 1982, and his pre-project work there, on what was to become Space Station Freedom, was very exciting. "We performed mission analyses, imagined flight operation scenarios, developed user requirements, and had lots of fun. In that instance, we enjoyed pushing the boundaries of what we thought might be accomplished, trying to determine what would be important, and responding to our perceptions of what the customer needed and wanted. At the time I left, we had just won the Phase B proposal for Freedom."

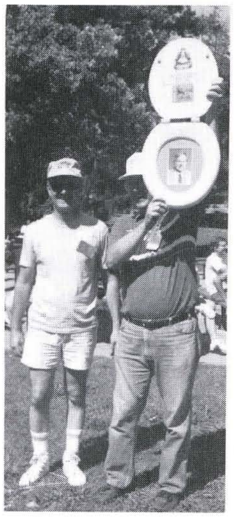
In 1985, when the opportunity came to work on Galileo, Jan enthusiastically took the opening on the Mission Design Team. He first worked on developing the Mission Plan for Galileo's interplanetary cruise. That came to an abrupt end with the Challenger tragedy. The next year was filled with brainstorming by the whole Project and the MDT was called upon to help evaluate the many options considered. The next couple of years were spent developing operating strategies for the Venus–Earth–Earth Gravity Assist mission. Jan also spent a few months performing budget exercises and staffing for the Comet Rendezvous Asteroid Flyby Project. He became Acting Team Chief in late 1987 and was officially appointed Team Chief in late 1988.

When not citing guidelines and constraints, Jan enjoys tournament chess (in which he is rated an "Expert"), playing softball and tennis, and reading "when I can find the time." Jan and his wife of nine years, Linda, share their elderly Santa Monica beach cottage with a dog, a cat, and a couple of rabbits. The Ludwinskis are endeavoring to restore the home to its former glory with lots of help from Linda's father (an electrician) and her uncles (a plumber and a carpenter). Their 18-month-old daughter, Lara, doesn't seem to be a big help with the construction yet, but Jan can wait. He's used to planning years in advance.









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The Galileo Messenger

Issue 25 September 1990

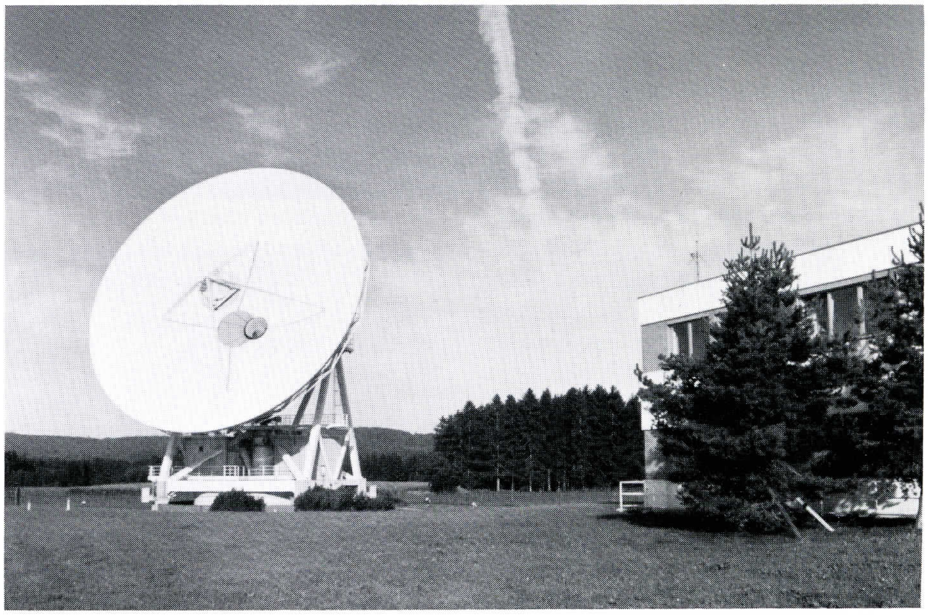
From the Project Manager

The Galileo spacecraft has had a nice, quiet summer. Sun-pointing attitude maneuvers have been performed monthly, and periodic propellant line flushing, general housekeeping, and cruise science memory readouts continued. Our fifth Trajectory Correction Maneuver (TCM) was expertly performed as planned on July 17 and required a velocity change of less than one meter per second.

The electrical power bus imbalance measurements indicated by telemetry have remained very stable. We are still working to determine if the buses are actually imbalanced or if it is just a problem in the sensing circuitry. If either bus is truly imbalanced, it likely means there is a leakage path through some component to the spacecraft chassis. Then, in a worst-case situation, a subsequent fault (short) in a component between the opposite "power rail" and chassis would cause a short across the power rails through the offending components. The fuses of one or both components would blow, permanently removing those components from the power bus. If the component was a mission-critical one, then its redundant partner would take over.

Even in this worst-case scenario, the spacecraft would remain completely functional. However, it could not tolerate a subsequent short in the critical component that had replaced its failed partner, if another leakage path again existed

—*See page 3*



The 30-meter antenna at the Weilheim Ground Station.

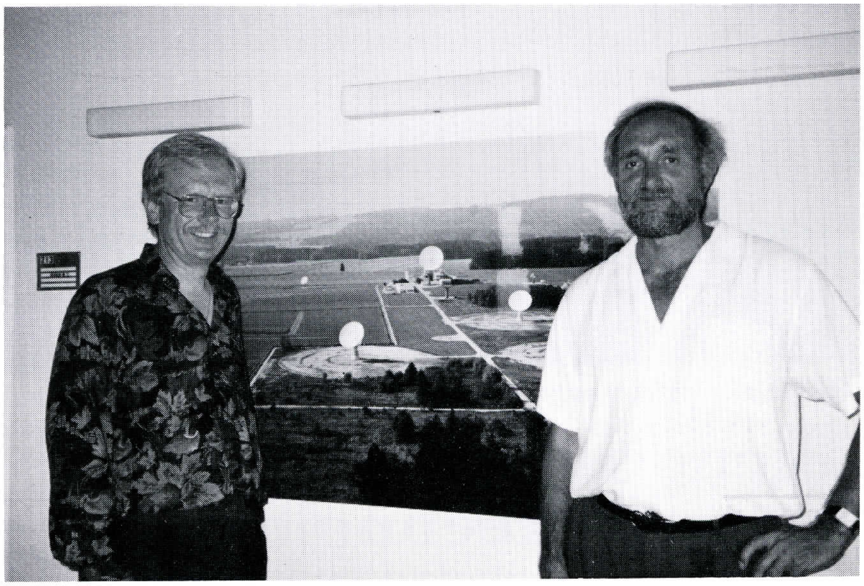
Blending American and German Technology

Beneath the Alps, nestled amongst the forests and farmlands of Bavaria, lies one of Galileo's most modern support facilities—the German Space Operations Center's (GSOC's) Weilheim Ground Station. JPL and the Deutsche Forschungsanstalt für Luft- und Raumfahrt e.V. (DLR), GSOC's parent organization, are preparing the Weilheim Ground Station for a communications test on September 24 and 26, 1990. To confirm that the ground station can communicate with the spacecraft, the test will verify the compatibility between Weilheim's transmissions and Galileo's detection and decoding of those transmissions.

Adding to the challenge of this test will be the current weakness of the spacecraft's signal. Since the high-gain antenna remains furled until next April, Galileo's signal is presently too faint for Weilheim's 30-meter antenna to receive data directly from the spacecraft. Consequently, one of the DSN's 70-meter antennas (at Madrid) will have to listen to Galileo and monitor its response to Weilheim's transmitted commands.

During the test, Weilheim will transmit NO-OP (no operation) commands to the spacecraft. Early in the test preparation phase, JPL's Guy Beutelschies determined that NO-OPs should be the commands transmitted, since they do not cause any spacecraft configuration changes and are easily confirmed in downlink telemetry. All a NO-OP causes Galileo to do is increment an onboard counter, which notes that a command has successfully

At JPL, Guy Beutelschies (far right) reviews preparations for the communications test with (from right to left) Betty Sword, Vickere Blackwell, David Durham, Ralph Johansen, and John McKinney.



At Weilheim, Herbert Wüsten (left) and Friedhelm Glasik discuss a photo of the ground station's antennas.

reached and been interpreted by the spacecraft.

Before the commands can be sent to Galileo, GSOC must first receive them and ready them for transmission. A few weeks before the test, JPL's Ralph Johansen worked with the Mission Control Team to generate and send to GSOC a tape containing a series of NO-OP commands. Since the tape might have been corrupted during mailing, GSOC personnel then printed the contents of the tape and faxed a copy back to JPL so Ralph could perform extensive comparison tests to make sure the information had been received properly. In addition, JPL's Betty Sword has been working with GSOC personnel to insure the overall readiness of the Ground Data System to support this test.

During the actual communications test, Herbert Wüsten, GSOC's Galileo Flight Operations Manager, will work with Hans Auer, Werner Hartl, Roger Walker, and Robert Fiedler to route the NO-OP commands on to Weilheim for transmission by the 30-meter antenna. However, Galileo cannot understand Weilheim's signals without additional help. The spacecraft requires commands to be Bi-phase-L (Manchester) coded onto the uplink pattern. This has called for a software modification to Weilheim's Command Modulator Unit (CMU) so it can modulate commands into a form Galileo can detect and decode.

The telemetry data received by the Madrid 70-meter antenna will be sent in real-time to JPL. At JPL, Kevin Flynn and Boyd Madsen will be monitoring these data, which will contain information assuring that the Galileo spacecraft is locked onto the uplink signal from Weilheim and that the "command count" increments after a NO-OP is sent.

The communications test is a warm-up for important future activities. Beginning in September 1991, GSOC, located in Oberpfaffenhofen, Germany (45 kilometers from Weilheim), will support Galileo with five Weilheim tracks per week. During these tracks, GSOC will be responsible for monitoring telemetry data, generating science data records, and commanding Galileo. The commands that GSOC can generate for transmission are non-interactive "Delayed Action Commands" (DACs) for the spacecraft's Fields and Particles instruments. Tracking support by Weilheim and GSOC will allow the Galileo Project to collect science data regularly and consistently throughout the Interplanetary Cruise phase of the mission.

As a part of this, the German Data Management Team will provide Experimenter Data Records (EDRs) and Supplemental Experimenter Data Records (SEDRs) to the Galileo Fields and Particles Science Investigators. Generated every two weeks, these records will contain the combination of all science data received by both the DSN and Weilheim, and will provide the Orbiter scientists with all the Fields and Particles data they will receive from their instruments.

Once GSOC Cruise Science support starts, GSOC will continue to serve Galileo until 60 days before its arrival at Jupiter. At that time, science data support will require that the spacecraft transmit at rates as high as

134,400 bps—higher than GSOC will support for Galileo. Similarly, during the second Earth encounter and the asteroid Gaspra flyby, the spacecraft will be transmitting at rates that are higher than GSOC's maximum supportable rate of 7,680 bps.

The GSOC Ground Station Complex at Weilheim has a panoply of antennas to support a variety of activities: the 30-meter antenna, for deep space missions such as Galileo; two 15-meter antennas, for near-Earth orbiting and geostationary satellites; and one 9-meter antenna and one 4.5-meter antenna, for meteorological and telemetry data acquisition. Armed with a pair of VAX computers and a host of up-to-date equipment, from cesium-beam frequency standard clocks to bit synchronizers, GSOC is prepared to support Galileo for many years to come.

GSOC has supported other missions besides Galileo—ROSAT (the most sophisticated X-ray telescope in orbit), Helios, and Viking. However, Galileo's weak signal, transmitted via its low-gain antenna, is what makes this compatibility test tricky for all involved. Weilheim's signal can reach Galileo, but Weilheim cannot receive any direct response. The antenna will be essentially "pointing blind," says Vickere Blackwell. "We are both confident and dependent on everyone doing his or her job properly."

— *Vickere Blackwell*

(PROJECT MANAGER from page 1)

on the opposite side to complete a short across the power rails. Our goal is to understand what is causing the imbalance indication before our upcoming November reviews.

We have been watching Magellan's problems with great empathy. Because of the commonality between the Magellan and Galileo Command and Data System (CDS) and Attitude and Articulation Control System (AACS) hardware, we must determine what implications Magellan CDS and AACS problems have for Galileo operations. We have also offered technical assistance to Magellan. While the hardware is common, the mission applications are very different. We have not identified any new concerns from the Magellan experience. However, the experience underscores the importance of remaining very rigorous and cautious in operating Galileo. We salute our Magellan colleagues for overcoming many problems to begin what is already seen to be an outstanding mapping of Venus.

The Galileo Flight Team has been very busy preparing the sequences for the upcoming Earth–Moon encounter and doing the Mission Operations System Design Verification for Jupiter operations. Very shortly, spacecraft operations will pick up and once again dominate our activities. Three small TCMs (6, 7, and 8) will be performed on October 9, November 13, and November 28, to make the final adjustments to the Earth approach trajectory to yield the required Earth gravity assist with a closest approach at 12:35 p.m. PST on Saturday, December 8. Starting in early November, we will have essentially continuous DSN tracking of Galileo that will provide continuous fields and particles data as Galileo approaches Earth through Earth's magnetotail. During Thanksgiving week, our Venus science data, including 81 pictures, which were stored on the tape recorder during the Venus encounter in early February, will be telemetered to Earth. From Thanksgiving to Christmas, we will have a bonanza of Venus, Earth, and Moon data to show the world. The coming holiday season promises to be the best yet for Galileans.

— *Bill O'Neil*

Galileo: Up To Date

The spacecraft continues to perform well. At present, the Ultraviolet Spectrometer (UVS), the Extreme Ultraviolet Spectrometer (EUV), the Magnetometer (MAG), and the Dust Detector Subsystem (DDS) are gathering cruise science data. Galileo is presently communicating at S-band using the low-gain antenna mounted along its -Z axis; the communication range and Sun-spacecraft-Earth geometry during this mission phase limit the telemetry rate to 40 bits per second. The spacecraft is now beyond 1 AU (149,668,992 km) from the Sun, and several of its thermal control heaters have been activated to keep equipment within acceptable temperature limits.

On June 8, the fifth Venus–Earth sequence-memory-program (VE-5), which controls planned sequence activities from June 11 through October 22, was successfully transmitted and received by the spacecraft. Special time windows were provided in the VE-5 sequence load to accommodate Trajectory Correction Maneuver 5 (TCM-5) and TCM-6, planned for July 17 and October 9, respectively. On July 17, the spacecraft successfully executed the TCM-5 maneuver, using its axial (Z) and lateral (L) thrusters to impart the required velocity change of less than one meter per second. The spacecraft performance throughout the maneuver activity was normal, except for the loss of the P1A thruster temperature transducer, which occurred during a planned pointing correction after the axial burn segment.

In addition to the TCM-5 maneuver, several Galileo periodic health and maintenance activities were performed, such as SITURNs, Retropropulsion Module (RPM) thruster "flushing," and telecommunications tests. The largest SITURN—or turn activity

to keep Galileo pointed within safe angles of the Sun—to date, about 19 degrees, was successfully accomplished on August 3. Other, smaller magnitude turns were performed in July and September. As part of the planned RPM maintenance, all the 10-newton thrusters were successfully flushed; system performance during these activities was normal. Several telecommunication tests have been successfully performed to collect trend information regarding the performance and operational characteristics of Galileo's telecommunication equipment, including the receivers, command detectors, and ultrastable downlink frequency source (USO).

Review of earlier collected MAG Memory Readout (MRO) data indicated the instrument experienced some anomalous MROs, resulting in the loss of some MAG cruise data. Investigative actions, consisting of MRO data analysis and instrument power cycling, revealed the anomaly was caused by a Magnetometer instrument programming error, which became evident under the unique condition of repeatedly using the program's optimal averager for an extended time period. This extended usage resulted in a memory overflow that caused corruption of the MAG executive program.

In August, special EUV MROs were performed to collect data from Comet Levy. The EUV successfully detected the presence of hydrogen in the comet's coma and tail.

The Project's Tiger Team continues to investigate the AC/DC bus imbalance anomaly that began in December 1989 and the anomalous Command Data Subsystem (CDS) critical-controller A power-on-reset (POR) telemetry indications. On July 19 and July 23, recurrences of the CDS POR telemetry indication were observed. The signature was the same as that observed in previous occurrences in February and April 1990. The Flight Team, as before, successfully reset the telemetry indications. The cause of the CDS POR telemetry indications is unknown, but was thought to be the result of electrical noise coupling from the 2.4-kHz power interface to the POR indication interface. However, subsequent ground testing with flight-like hardware did not confirm noise coupling as a likely possibility. Other possibilities, including faulty solder joints, electronic part anomalies, and marginal circuit component performance, are currently being investigated. The AC/DC bus imbalance effort has been unsuccessful in isolating the cause or causes for the observed abnormal readings. No consistent correlation has been found between the imbalance measurements and any other spacecraft measurement; all power-related and other subsystem measurements continue to be normal. Spacecraft operations are not impaired as a result of these two anomalies.

The sequence design effort is continuing in support of the VE-9 and VE-11 sequences. VE-9 covers spacecraft activities from October 22 to December 7 and incorporates TCM-7, TCM-8, and TCM-8A. It also includes the playback of Venus science data that Galileo collected in February 1990, a Probe checkout, the science instrument turn-on and calibration in preparation for the first Earth flyby in December 1990, and some Earth approach science data collection. VE-11, the most complex sequence to date, covers from December 7 to December 17 and includes intensive science data collection associated with Earth closest approach and Earth–Moon data collection.

In addition to the spacecraft and sequencing efforts, the Project completed its preparations for the German Space Operations Center (GSOC) S-band uplink compatibility tests with the Galileo spacecraft; all necessary equipment, plans, and procedures are approved and in place. The tests will be conducted in late September 1990 using the German Weilheim tracking station.

The Ground Data System (GDS) has been continuing its efforts to improve ground software and has recently delivered a major software update to the Project. Significant improvements in operability and reliability were incorporated to the sequence design program set including SEQCOMP, SEQGEN, and POINTER.

The Project has initiated actions in support of the Earth 1 flyby readiness review and the Mission Operations System Design Verification Phase II Review to be held in early November 1990.

— Matt Landano

*Galileo Mission Summary**

Distance from the Earth	81,157,000 kilometers (50,428,620 miles)
Distance from Jupiter	843,850,100 kilometers (524,344,110 miles)
One-Way Light Time	4 minutes, 33 seconds
Velocity Relative to the Earth	14.56 kilometers per second (32,560 miles per hour, mph)
Velocity Relative to the Sun	22.43 kilometers per second (50,173 mph)
Spacecraft–Sun Angle	3° off Sun (leading)
Spacecraft Spin Rate	3.15 revolutions per minute
Downlink Telemetry Rate	40 bits per second (low rate) using Low-Gain Antenna 1
Spin Configuration	Dual spin—cruise mode
Powered Science Instruments	Ultraviolet Spectrometer, Extreme Ultraviolet Spectrometer, Dust Detector, Heavy Ion Counter, and Magnetometer
RTG Power Output	547 watts

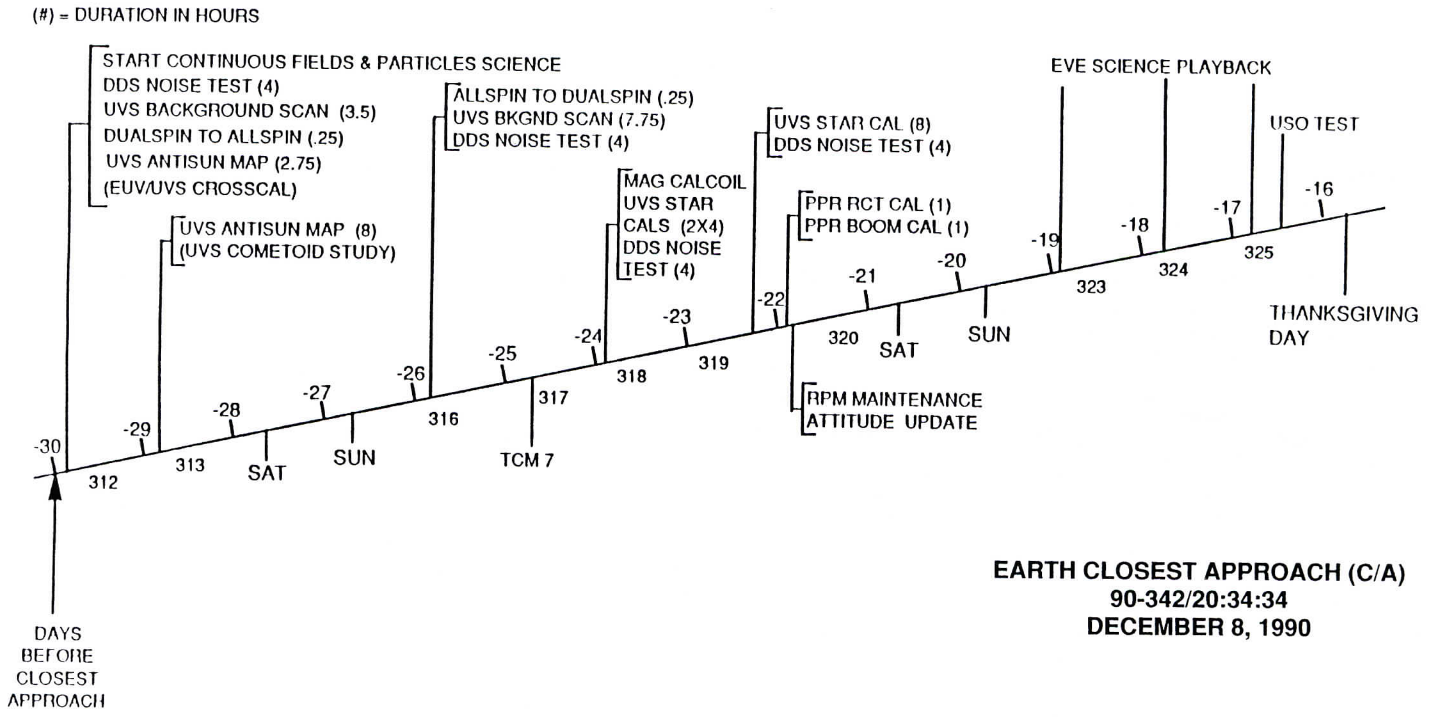
**All information is current as of September 14, 1990.*

The Project Science Group

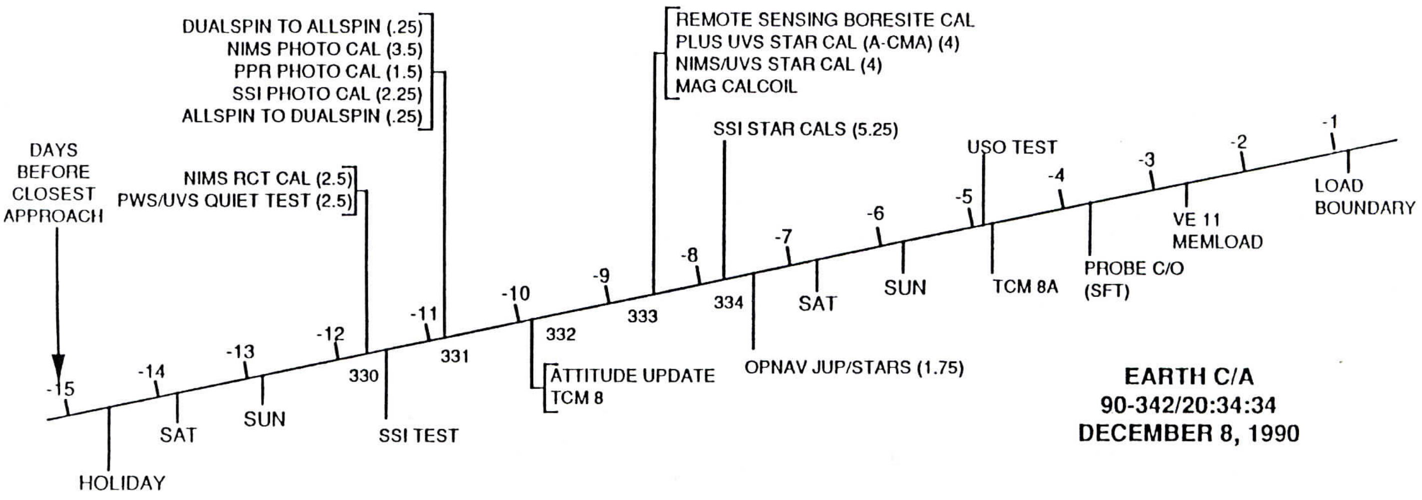
Galileo's Project Science Group (PSG) met on August 15 and 16, 1990, at JPL. The PSG is the Project's highest level advisory body concerning itself with scientific objectives and strategy. Chaired by the Project Scientist, with the Probe Scientist as deputy, it consists of the instrument Principal Investigators (PIs), Team Leaders of the imaging team and the two radio science teams, and Scientific Working Group Chairmen. Its meetings are attended by PSG members, Interdisciplinary Scientists, Co-Investigators, and Team members interested in the specific topics being addressed. PSG meetings, usually held two to four times a year, serve the purpose of communicating with the extended Galileo science community, providing a forum for the Project to discuss spacecraft status, mission status, technical problems, and funding problems, and for the PSG to offer advice on scientific issues affecting their investigations and the Project as a whole.

During the development phase of Galileo, the PSG played an active role in spacecraft definition and instrument accommodation. Following the Voyager Jupiter encounters, they reviewed and recommended a number of modifications and additions to experiments to take advantage of the new information. And, of course, they played a major role in the several reprogramming exercises forced on the Project by delays and funding problems in the early 1980s.

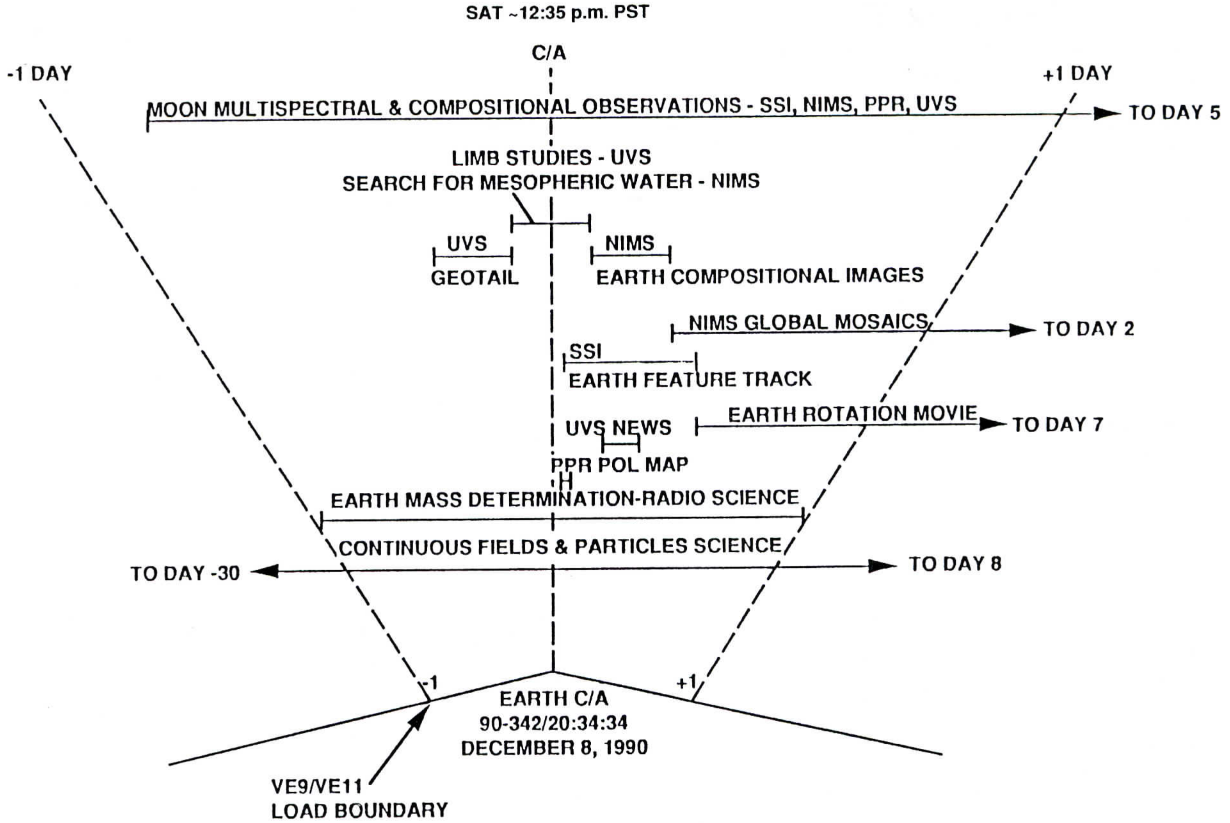
Since launch, the PSG has focused on the results of early instrument checkouts and re-



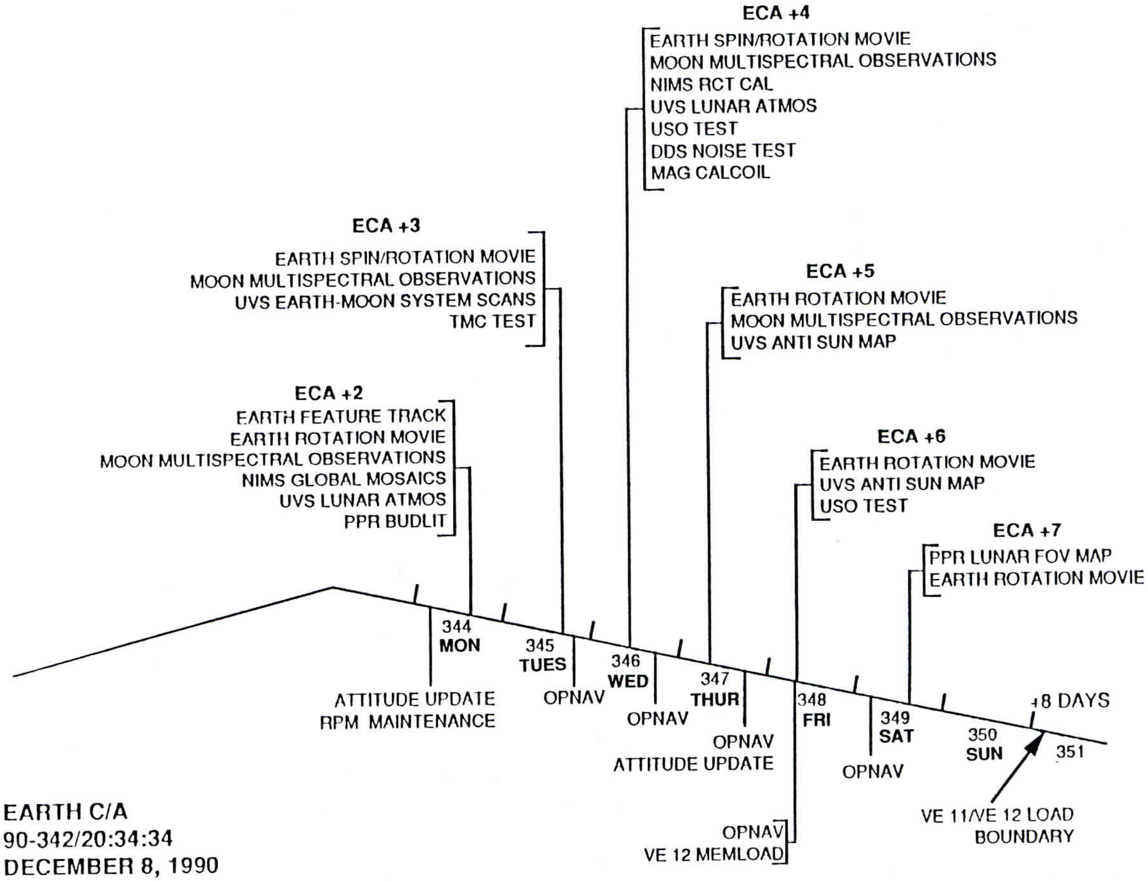
Earth–Moon 1 activities (-30 to -15 days)



Earth–Moon 1 activities (-15 to -1 days)



Earth–Moon 1 activities (-1 to +1 days)



Earth–Moon 1 activities (+1 to +8 days)

viewed plans for Venus, cruise, and Earth–Moon science. The August 1990 meeting included discussions of the upcoming Probe checkout during the Earth encounter sequence, a review of plans for the Earth encounter program loads developed by the Science Requirements and Operations Planning Group (SROP) (see timelines), and discussions of early science results from the various experiments. A special feature on the second day of the meeting was a briefing by Dr. Nick Schneider of the University of Colorado on the current state of the Jovian plasma torus, based on observations coordinated by the International Jupiter Watch. This included a spectacular video of the torus as seen by light emitted from sulfur ions bombarded by electrons. Following the December Earth encounter, the PSG's attention will shift to plans for the flyby of the asteroid Gaspra in October of 1991, preliminary planning for selecting the Jupiter orbital tour, and preparations for the detailed work associated with planning the Jupiter system observations.

Chairing the PSG is a real challenge. Dr. "Robby" Vogt, former JPL Chief Scientist and an early Voyager PI, once likened the job to organizing a school of barracuda. However, it is also rewarding, bringing together as it does the diverse scientific elements of Galileo's fascinating array of investigations. Over the years, the PSG has become something of an extended family, working through good times and bad with the Project toward our shared goal of finding out what makes the Jupiter system tick.

—Torrence Johnson

Providing Real-Time Support

Real-time, near-real-time, and non-real-time may seem like very strange concepts, but to the four flight operations teams in the Flight Control and Support Office headed by Joe Gleason, they signify a very real division of duties. The four teams divide their functional responsibilities as indicated by their names: Mission Control, Deep Space Network Operations, Multi-Mission Control, and Computing Center Operations and Data Management

In the busy realm of real-time, the Mission Control Team (MCT) thrives. Led by Bob Warzynski, this Team is responsible for controlling the Ground Data System (GDS), commanding the spacecraft through operation of the GDS, providing the tools for operating the spacecraft, and monitoring the data being received. Organization is the key. Members include the Mission Controllers, who coordinate the overall real-time operations; the System Computer Operators, who are at the "controls" and communicate with Galileo; the Data Technicians, who disseminate the data; and a real-time support element that works behind the scenes. During critical operations, the real-time members of the MCT must staff the real-time stations 24 hours a day.

To organize and orchestrate the real-time work, this real-time support element of the MCT creates an integrated sequence of events that is the operations scenario used by the mission controllers to execute the mission plans. In addition, the real-time support personnel coordinate the generation and approval of spacecraft commands and generate several longer range Project Schedules. These include a weekly listing of space flight operations; a monthly ground events profile outlining the Project's activities; and the integrated mission operations profile, which extends over the whole mission and views the Project's activities from the "big picture." The real-time support personnel are also responsible for negotiating and scheduling the Deep Space Network (DSN) antennas used to track and command the spacecraft.

The DSN supplies all the equipment (the antennas, the hardware, and the personnel to operate them) required to radiate commands, and acquire Galileo data. They have provided a multimission team, the Network Operations Control (NOCT), to work with the Project to ensure that its needs are met. The three NOCT engineers, Bob Hollingsworth, Bob O'Connor, and Michele Andrews, keep the DSN informed of Galileo requirements and relay specific operating instructions to the DSN sites to assure proper support. Galileo's NOCT is just part of a "huge organization independent of the Project, but committed to supporting Galileo in all its endeavors," notes Gleason.

The second of the two multimission teams supporting Galileo Flight Operations in real-time is the Multi-Mission Control and Computing Center Operations (MOCT). The MOCT is responsible for processing and displaying the data to and from the spacecraft, and providing the facility space in which the Project performs its operations. Jose Coito and Joe Gomez lead the MOCT as Facility Project Engineers.

With a slightly longer range view, the Data Management Team (DMT), headed by Steve Spohn, works with near-real-time and non-real-time products, providing the Galileo data in usable formats to engineers and scientists. While the MCT generates and sends commands to Galileo, the DSN radiates these commands and retrieves the spacecraft's responses, and the MOCT processes

Joe Gleason (second from left) gathers with the members of his Flight Control Support Office: Billie Weir, June Loiseau, and Nino Lopez (from left to right).

the responses, the DMT formats the responding data into Engineering Data Files, Experimenter Data Records, and Supplemental Experimenter Data Records for the Principal Investigators and instrument representatives. The DMT also provides the engineering data to the Orbiter Engineering Team for analysis of spacecraft performance and trend prediction. All together, these products allow a "quick look" by the Project in near-real-time at the data coming back from Galileo and provide an archival database of all data received.

The Flight Control Support Office runs smoothly under managers Joe Gleason and Nino Lopez, Administrative Assistant Billie Weir, and Secretary June Loiseau. Gleason points out, "All together, the Office and Flight Operations work to meet the Project's goals by executing the mission plans."

An outspoken, jovial manager of the Flight Operations teams, Joe runs a well-organized operation. He has also long been involved with launch operations of some kind. After a stint with the Navy, Joe worked for Pan Am World Airways Guided Missile Range Division at Cape Canaveral as operations manager for NASA launches, and before that as a Missile Tracking Ship Operations Manager in the South Atlantic. It was still early on in missile development and the learning curve was steep. Joe's ship was to be stationed about three miles away from the ocean target reentry site. Joe relates, "the first time, we were three miles away and the missiles dropped all around us. After that, we stayed at the target site and we were fine . . . the missiles never came close." Joe continued with Pan Am, tracking some of JPL's early spacecraft that were launched from the "Atlantic Missile Range," which eventually became the Eastern Test Range of today. JPL management then convinced Joe to join them on the West Coast, and he happily did so. "It's safer here," he said.

A major difference between his earlier days in launch operations and his present job of helping to track Galileo is the amount of time available to make decisions. "For Cape launches," Joe says, "you had to be sure in the final seconds that the launch is right or you could lose the vehicle. For deep space missions, whatever the data tells you happened is minutes or hours old, which gives you the time to come to a well thought out recovery choice."

When away from the Lab, Joe can often be found playing in the JPL softball league, in which he admits to being a one-dimensional player. In his younger days, though, his South Missouri team went to the Mid-West Regional fast pitch championships for two years, and a slow pitch team that he played on in Central Florida went to the world open championships four years running. His first year with that team, he batted an impressive .750.

Joe and his wife, Joan, have just seen their youngest child graduate from high school. Their four children, Laura, Tim, Tom, and Leslie, can be proud of their dad and of all the Galileo Flight Team, who help keep the flight operations on track.

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The Galileo Messenger

Issue 26 December 1990

From the Project Manager

We have just had our first Galileo science press briefing. Several Galileo scientists presented and described their first look at the data Galileo obtained at Venus. Recall that we had to store the Venus data on the spacecraft's tape recorder until Galileo got close enough to Earth to transmit at a high data rate over one of its low-gain antennas.

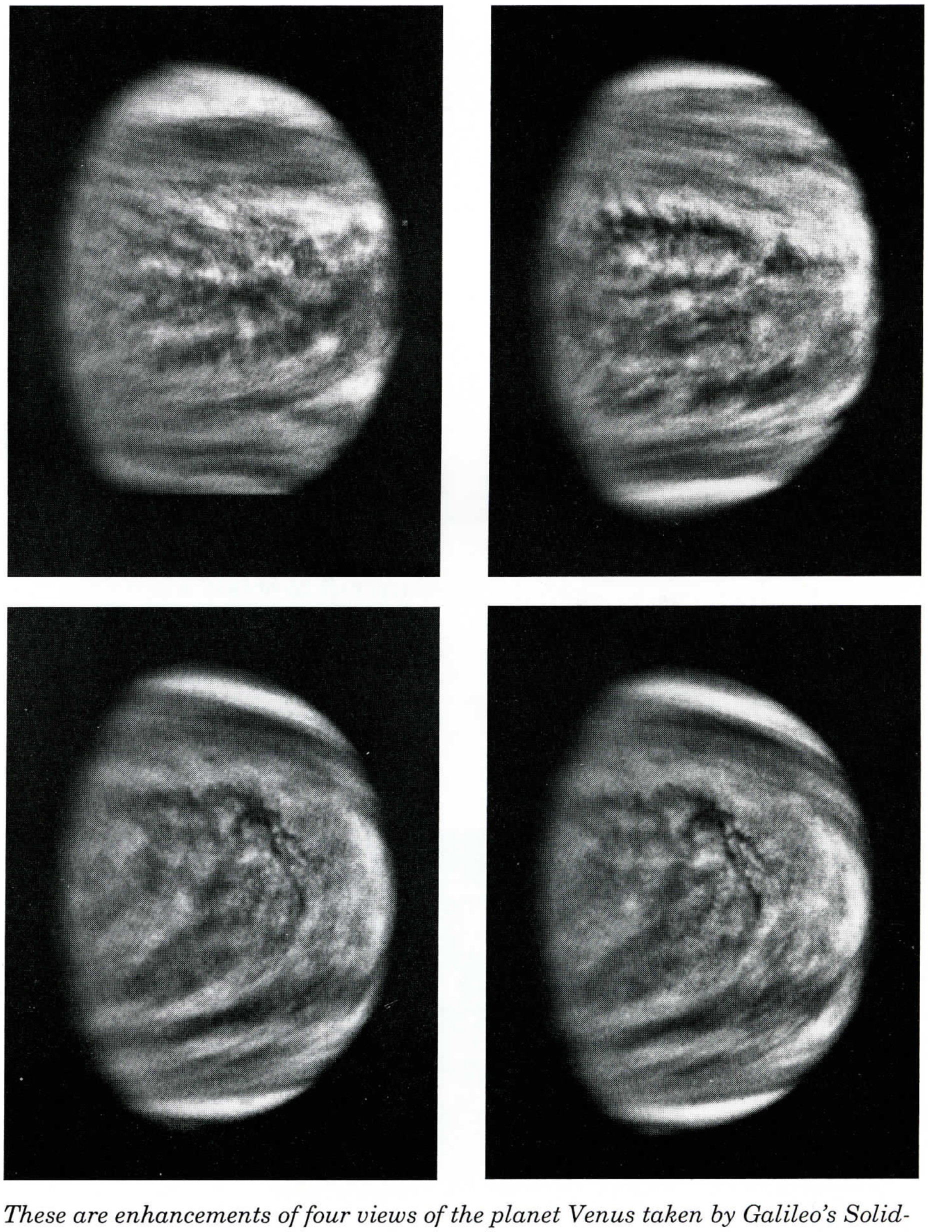
The broad spectrum of information about Venus obtained by Galileo in this very limited, "first" encounter is awesome. It is a wonderful confirmation of the ability of the Galileo Orbiter's instruments to thoroughly investigate the Jovian system.

During the upcoming Earth encounter, Galileo will make extensive measurements of the environment in Earth's neighborhood in space, and will acquire many exciting observations of the Earth and Moon in the ultraviolet, visible, and infrared spectrums.

Of course, we must remember that the only reason we went to Venus and the only reason for flying past the Earth (twice!) is to get to Jupiter. In that regard, Galileo just completed its last Trajectory Correction Maneuver before Earth encounter. It was performed excellently, just as all the others have been. No further actions are required on the ground or spacecraft to achieve the required first Earth gravity assist; it is already assured. Very

— See page 8

Venus Through Galileo's Eyes



These are enhancements of four views of the planet Venus taken by Galileo's Solid-State Imaging Subsystem (SSI) at distances ranging from 1.4 to 2 million miles as the spacecraft receded from Venus. The pictures in the top row were taken two hours apart about four days after closest approach. The faint Venusian cloud features are especially clear. A high-pass filter was applied to bring out broader global variations in tone. The bright polar hoods are a well-known feature of Venus. Of particular interest to planetary atmospheric scientists are the complex cloud patterns near the equator, in the vicinity of the bright subsolar point, where convection is most prevalent.

The Sequence Team: Interpreting for Galileo

Clear, comprehensible communication with the spacecraft is essential to Galileo's mission. However, the written and spoken desires of Galileo's scientists and engineers are incomprehensible to the spacecraft. Ordering, defining, and translating those desires into Galileo's computer language can be quite a challenge—a challenge well met by Galileo's Sequence Team.

The communication cycle generally begins with a request from the Orbiter or Probe Engineering Team or the Science Office. The Mission Design Team (MDT) coordinates all these requests to allow Galileo to do as much as possible without endangering itself or its supplies (for example, propellant). Sometimes the requests find their way to the Sequence Team still written as narrative, but generally the MDT combines all requests into a Cruise Plan file.

The Cruise Plan then comes to the Sequence Team. Because they deal at a greater level of detail than the MDT, often the Sequence Team needs to elicit more information from the originators. The Sequence Team has created a variety of software programs, with automatic checking functions, that begin to translate these Cruise Plans into actual sequences of commands for Galileo. After performing a series of checks and then being satisfied with the sequence of commands, the Team passes the sequence on to others to ensure that additional mission constraints have not been violated and for the scientists to verify that their desires will be met by these commands. The Team takes all that input and creates a second and final iteration.

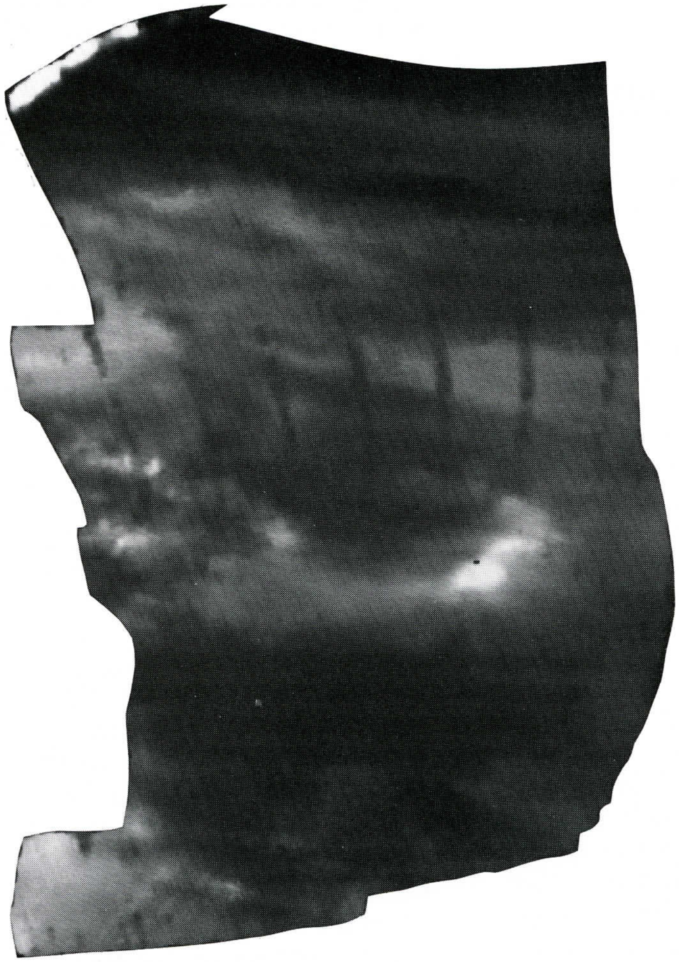
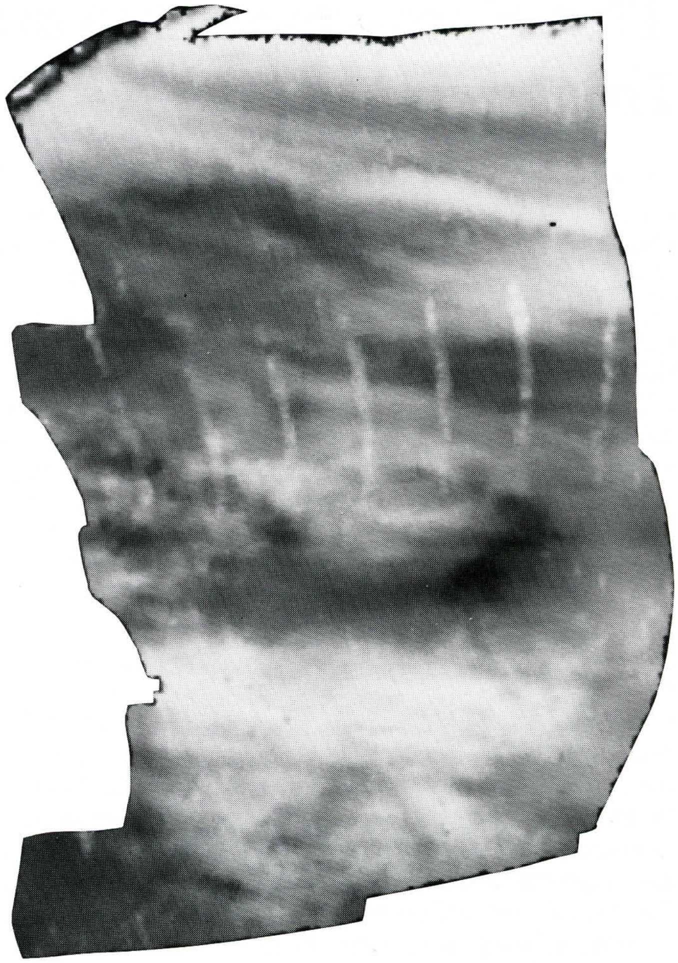
This scenario is followed for all large sequences. Often, though, sequences need to be created much more quickly, especially when creating a Trajectory Correction Maneuver (TCM) for the Navigation Team and the Orbiter Engineering Team (OET). For a TCM, the Navigation Team requires the spacecraft to obtain a certain change in velocity; the OET then designs how the spacecraft should perform the TCM. In such an instance, the Navigation Team starts the process one to two weeks before Galileo needs to perform a maneuver, after which the OET takes one to four days to design the maneuver. The Sequence Team then "builds" the commands within one to four days, depending on how much time they have.

These processes have served Galileo well over the mission's first year. Jim Erickson, Sequence Team Chief, expressed, "This has always worked very well. In fact, this is the way we generate all commands, except for a few real-time commands sent through the Mission Control Team."

Even with *near*-real-time commands, the Sequencing Team might get involved. Sometimes the Project needs quick turn-around work. Jim indicated, "In that case, we only perform one iteration. We generally build the commands in a day and the sequence is reviewed in a Command Conference. We send a tape to the Mission Control Team and they send it to Galileo. Especially when the turnaround is so rapid, it's important to check the Project's command constraints because of the possibility of harming the spacecraft or violating constraints and rules."

Each week, the Sequence Team delivers at least one product and is working on two others in parallel. As many as four or five sequences could be with the Team at any

The Sequence Team serves as a vital link in communicating with the spacecraft.

These images are two versions of a near-infrared map of lower level clouds on Venus' night side, obtained by the Near-Infrared Mapping Spectrometer on February 10, 1990. With a spatial resolution of about 13 miles, this is the sharpest image ever obtained of the mid-level clouds of Venus. The image to the left shows the radiant heat from the lower atmosphere (about 400°F) shining through the sulfuric acid clouds, which appear as much as 10 times darker than the bright gaps between clouds. This cloud layer is at about 170°F. This high-resolution map covers a 40-degree-wide sector of the Northern Hemisphere. The several irregular vertical stripes are data dropouts. The right image, a modified negative, represents what scientists believe would be the visual appearance of this mid-level cloud deck in daylight, with the clouds reflecting sunlight instead of blocking out infrared from the hot planet and lower atmosphere. Near the equator, the clouds appear fluffy and blocky; farther north, they are stretched out into east–west filaments by winds estimated at more than 150 mph, while the poles are capped by thick clouds at this altitude.

time. During encounter, that number may increase to 12 a week.

For example, in preparation for the upcoming Earth encounter, the Team is preparing TCM-8: a sequence for which the Project only has one week to prepare. The maneuver requires the latest possible navigation data, hence the short turnaround. Because Earth's gravitational assist will amplify all deviations from a perfect trajectory, a small adjustment at this point could save 500 times the fuel that would have to be expended after flyby if no TCM were performed. As Galileo's 1995 arrival at Jupiter nears, the time for sequence preparation will compress. Therefore, staying in practice on quick turnaround TCMs is valuable.

"It is easier between encounters," Jim commented. "During that time, we prepare for long-range events. We also use this time to create sequences that could be used for any possible contingencies or anomalies. We review past performances, examining what we might have done differently. In general, we sharpen up to get ready for the next encounter or maneuver and for Jupiter operations."

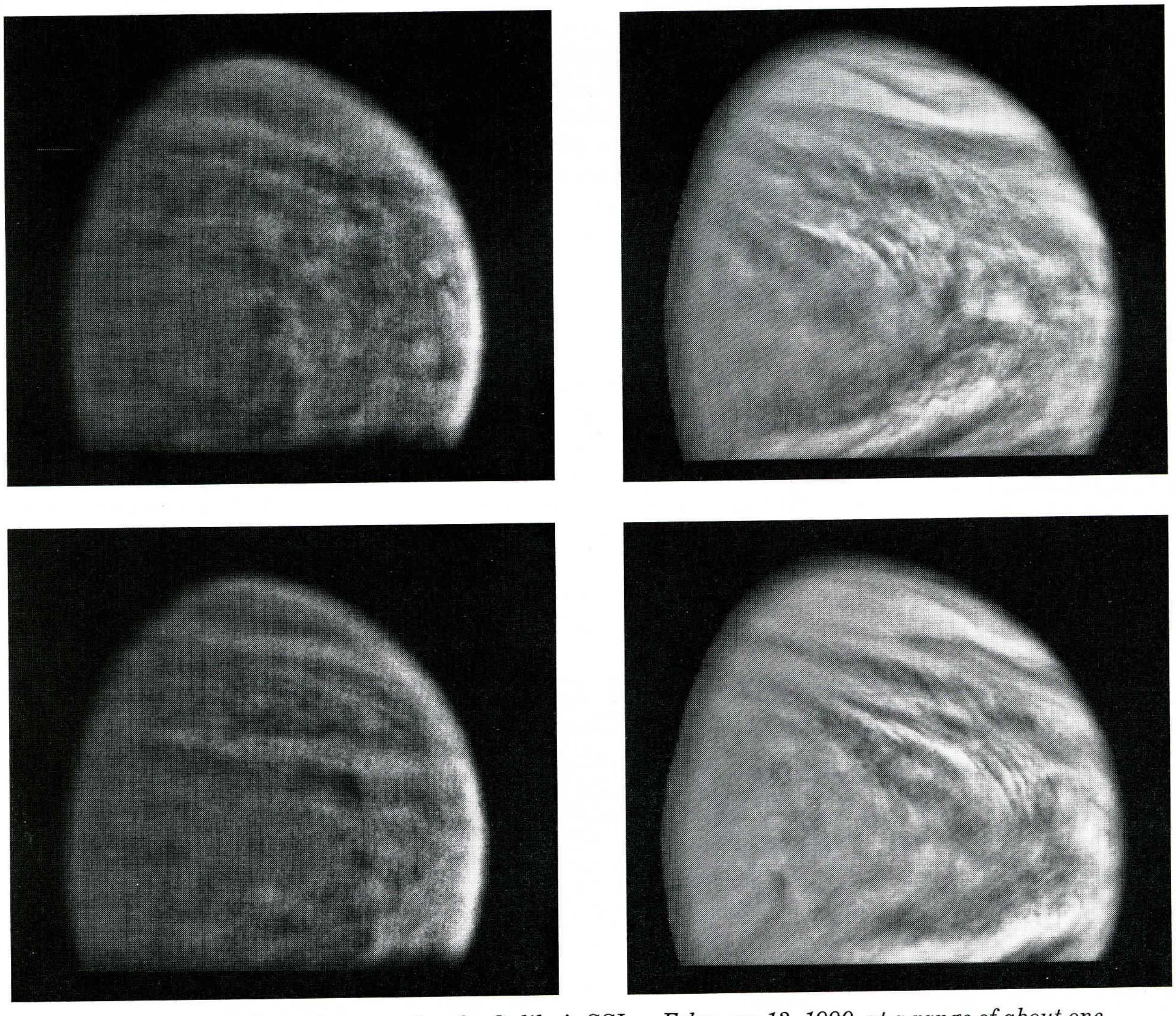
One such long-range event will be the High-Gain Antenna deployment next April. This is one of the most important sequences the Team has had to develop. Such an event has never occurred before, and no software is available to automatically check this sequence for certain errors. This, coupled with several unique requirements, makes the deployment a certain challenge for the Team. Jim, however, is not worried: "This is an excellent team. I have never worked with a better group of people in my life."

Each of the thirty-four people on the Team specialize in one of five sequencing functions. One group takes the Cruise Plan and other requests and merges them to create the sequences of commands

that will eventually cause Galileo to perform the desired function. Another group keeps an eye on the scan platform and how these proposed commands will affect it. A third group translates these sequences into the binary code, the zeros and ones, that Galileo can understand. Analyzing the telecommunications implications of the sequence falls under the cognizance of other individuals. Yet another group creates a graphic representation of the commands, a timeline, so that the Flight Team knows exactly what Galileo will be doing at any given moment. The Sequence Integration Engineers oversee organizing all this work. Meanwhile, in the background, other members of the Sequence Team work diligently to fine tune the Team's software. Jim summed up the group's outlook: "We are a service organization. We take other people's desires and create commands to have the spacecraft satisfy those desires."

Some of Jim's responsibilities as Team Chief include acting as a liaison with the Engineering Office, and overseeing long-range plans, future training, future staffing for Jupiter operations, budgets, product delivery, and special task preparation. All these tasks involve lots of meetings. Preapproval meetings are required so that the Sequence Team only works on Project-approved sequences. Command Conferences are called to review each Team product, including the semi-monthly Cruise Plans and weekly Team products.

Since Jim keeps his eyes on long-range planning, his Deputy



These images of Venus' clouds were taken by Galileo's SSI on February 13, 1990, at a range of about one million miles. The smallest detail visible is about 20 miles. The top images were taken six hours later than the bottom ones. The two left images show Venus in near-infrared light. Sunlight penetrates through the clouds more deeply at the near-infrared wavelengths, allowing a view near the bottom of the cloud deck. The westward motion of the clouds is slower (about 150 mph) at the lower altitude. The clouds are composed of sulfuric acid droplets and occupy a range of altitudes from 30 to 45 miles. The images have been spatially filtered to bring out small-scale details and de-emphasize global shading. The filter has introduced artifacts (wiggly lines running north–south) that are faintly visible in the infrared image. The two right images show, in violet light, the state of the clouds near the top of Venus' cloud deck. A right-to-left motion of the cloud features is evident and is consistent with westward winds of about 230 mph.

Team Chief, Bob Gustavson, handles the day-to-day responsibilities of the Team, including scheduling and personnel.

When Jim is not reviewing, approving, and planning Sequence Team activities, most of his free time is occupied by Robyn, his two-year-old daughter. He and his wife, Emily, spend their weekends with Robyn at the zoo and the park. When Robyn is napping, he can always find something to "fix" in their 60-year-old Glendale house. He reminisces, "I used to spend my weekends scuba diving, camping, or playing basketball with my friends from college."

Jim worked his way through college as an L.A. Department of Water and Power meter reader, learning to avoid angry dogs and homeowners. Of his alma mater, Harvey Mudd College, Jim cites a study declaring it "the best engineering college in the nation." In 1975, he was awarded a bachelor's degree in Physics, which, he notes, is "a license to know a lot about everything, but not enough to assure you of a job in anything."

Apparently that adage proved wrong, since Jim began working at JPL even before graduation. Initially he worked in hardware, working on the Multimission Control and Computing Center, even installing loudspeakers in Buildings 230 and 264. Then in 1977, Voyager beckoned and Jim helped to develop the ground data information system.

Jim transferred to the Galileo Project in 1979, later becoming the End-to-End System Engineer for downlink functions. During that time, he earned an MBA from West Coast University in Program Management and Finance. After the Challenger tragedy, Jim moved over to the Mars Observer Project as the Ground Data System engineer. The next year, he was able to come back to Galileo as Sequence Team Chief.

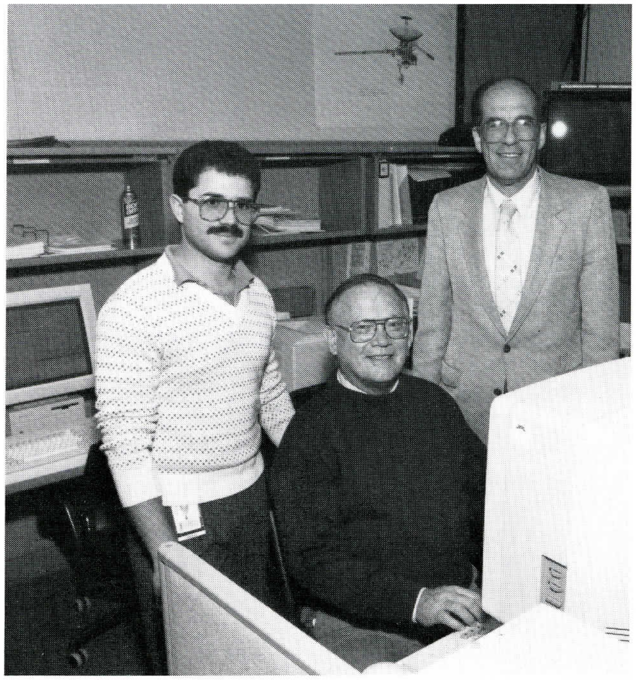
Keeping the Lines of Communication Open

Galileo collects data on its journey to Jupiter and transmits signals that are received by antennas on Earth. Soon after the signals are received, the Project's scientists and engineers receive printouts or computer files of information they can study and analyze. How do those bits of data received at the Deep Space Network become a graph on a scientist's desk? Behind the scenes, the Multimission Control and Computing Center creates the necessary lines of communication.

The Multimission Control and Computing Center (MCCC, or "M-C-cubed") Telemetry System acquires raw telemetry data from the Deep Space Network (DSN). After performing an elaborate, first-level processing, data are sent to the Project's printers and monitors, to the Probe Telemetry Processor, and to the Galileo Test Bed. This distribution makes engineering and science "housekeeping" data available to the Mission Control Team, Orbiter and Probe Engineering Teams, Science Teams, and throughout the Project staff. In addition, the low-rate science and engineering data are sent via tape to the MCCC Data Records Subsystem; and the high-rate science data (for example, images) are sent via tape to the Multimission Image Processing Laboratory (MIPL). These Telemetry and Data Records Subsystems, as well as the Multimission Operations Control Subsystem, Multimission Command Subsystem, Multimission Simulation Subsystem, and the General Purpose Computing Capability, are all implemented, maintained, and operated under the management of the Flight Projects Support Office (FPSO).

As its name implies, MCCC supports multiple missions, Galileo being only one of them. Still, MCCC caters to each of its customers, creating specific products and services for each project. For example, several things were done in preparation for Galileo's launch. All tape and disk recorders on the Galileo MCCC Telemetry Subsystem were refurbished or replaced. Most of these had been installed before the Voyager launches in 1977. Edwin Gatz, Flight Projects Support

— See page 8



Jose Coito, Ed Gatz, and Mel Pinck view Galileo images of Venus on an MCCC workstation.

Galileo: Up To Date

The Galileo spacecraft continues to perform well. Two Trajectory Correction Maneuvers (TCM-6 and TCM-7) were successfully completed on October 9 and November 13, respectively. Both maneuvers were executed using the axial (Z) and lateral (L) thrusters. Spacecraft performance during these maneuvers was excellent and near predicted levels.

In addition to the maneuvering activity, several other important activities were successfully completed, including loading the VE-9 program, which controls the spacecraft's activities from October 18 through December 7. These activities comprise the retraction of the Plasma Subsystem sunshade; the continued collection of cruise science data; special navigation operations; periodic health and maintenance checks (SITURNs, Retropropulsion Module thruster "flushing," and Attitude and Articulation Control Subsystem calibrations); and power on and checkout of the science instruments for the Earth encounter.

The Plasma Wave Subsystem (PWS), Energetic Particles Detector (EPD), Photopolarimeter Radiometer Subsystem (PPR), and Plasma Subsystem (PLS) were successfully powered on. Operations of the PWS and PPR were without incident; power consumption and thermal profiles were near anticipated levels. Shortly after the EPD and PLS were powered on, some unexpected events were observed. One of the EPD's low-energy detectors indicated very high noise counts, possibly indicative of a failing detector. Commands were sent to raise the threshold level of this detector and monitor its noise performance at the new level. Subsequent analysis by the Principal Investigator resulted in reduced concern for the detector's health and safety, and the threshold was lowered to its original value. The unexpected PLS event was thermal related in that temperatures in excess of predicted levels were observed shortly after power on. The thermal performance was closely monitored by PLS engineers and, subsequent to an intensive analysis, the PLS high voltage was powered off; temperatures were then noted to drop to safe levels. Operation of the PLS during the Earth encounter phase is presently being evaluated by the Principal Investigator.

The Extreme Ultraviolet Spectrometer (EUV) experienced an anomaly evidenced by no photon counts being recorded when the instrument was commanded to its encounter mode. Subsequent memory readouts indicated two bits in a single byte were corrupted. Although the memory locations were different, this memory corruption is similar to that observed in the December 1989 EUV checkout. The Principal Investigator rapidly recreated the same symptoms on the test vehicle at the University of Colorado and requested a test-verified software "patch." The EUV memory was successfully "patched" to reset the instrument to its encounter data-taking mode, and proper operation was restored. The cause of the EUV anomaly is being vigorously investigated by the Principal Investigator.

The AC/DC bus imbalance and the Command Data Subsystem (CDS) power-on reset (POR) telemetry indication anomalies are still being observed. The ninth despun CDS Critical Controller 2A POR occurred. The signature of this event was the same as that observed in the previous occurrences in February, April, and July 1990. Possible causes include a faulty solder joint, electronic part failures, marginal component performance, and slip-ring debris. The POR signal is normally used to inhibit Critical Controller commanding when a real POR signal is present. However, problems in selected electronic circuitry or in the telemetry latch device could produce an anomalous telemetry indication. In all occurrences, recovery from this POR was completely successful, indicating the event was not caused by a permanent failure in the CDS. The CDS personnel recently developed a software method to help determine whether the telemetry latch device is "faulty" or the circuitry is actually detecting a transient "POR signal" on the interface.

The AC/DC bus imbalance measurements continue to exhibit some activity. The AC measurement fluctuations were relatively small, varying between 1 and 3 volts, but always reading above 45 volts, indicating a leakage resistance path to chassis between 100 and 500 ohms. The DC measurement exhibited fluctuations of

*Galileo Mission Summary**

Distance from the Earth	17,790,470 kilometers (11,054,4900 miles)
Distance from Venus	163,162,570 kilometers (101,384,520 miles)
One-Way Light Time	1 minute, 4 seconds
Velocity Relative to the Earth	9.86 kilometers per second (22,050 miles per hour)
Veolicty Relative to the Sun	27 kilometers per second (60,410 miles per hour)
Spacecraft–Sun Angle	12.5° off Sun
Spacecraft Spin Rate	3.15 revolutions per minute
Downlink Telemetry Rate	1.2 kilobits per second (Low-Gain Antenna 1)
Spin Configuration	Cruise mode, dual spin
Powered Science Instruments	Dust Detector Subsystem, Energetic Particles Detector, Extreme Ultraviolet Spectrometer, Heavy Ion Counter, Magnetometer, Plasma Subsystem, Plasma Wave Spectrometer, Photopolarimeter Radiometer, and Ultraviolet Spectrometer
RTG Power Output	545 watts

**All information is as of November 16, 1990.*

about 14 volts, dropping from about 18.5 to about 4 volts. These fluctuations occurred over a one-hour period and during a time of no spacecraft electrical load switching, mechanical motion, or thermal environmental changes. All other power-related and subsystem telemetry continues to be normal. Tests to better characterize the Power/Pyro Subsystem telemetry sensor performance under both nominal and faulted conditions are in process.

The Plasma Subsystem pyro-actuated sunshade was successfully retracted on November 1. All spacecraft pyro-related telemetry was as expected. Indication of sunshade retraction was quickly observed by the Attitude and Articulation Control Subsystem acquisition-sensor temperature data and later by PLS temperature measurements.

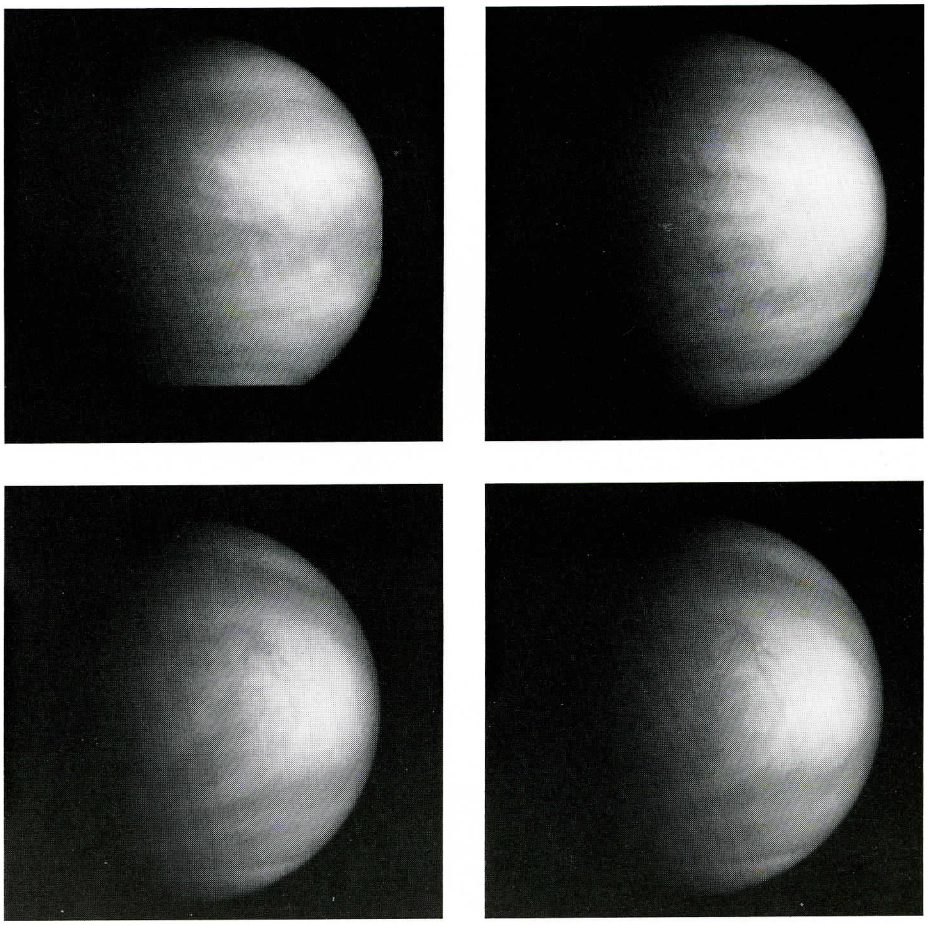
Special navigation activities, Delta Differential One-Way Ranging (ΔDORs), using all three DSN sites were conducted this fall in support of Earth navigation. Twenty-one of these passes have been successful. A ΔDOR is another navigation data source—used in addition to Doppler and ranging data—to better determine Galileo's exact location.

Several recent activities focused on verifying communications with the spacecraft. A major uplink compatibility test was successfully completed in September. During each of two tests, 16 no-operation (NO-OP) commands were transmitted to the spacecraft from the Weilheim, Germany, tracking station under control of the German Space Operation Center (GSOC). The two uplink tests were nearly identical, except that the second test also included ranging modulation on the uplink. The Galileo Flight Team in the Mission Support Area at JPL used downlink telemetry via the Deep Space Network's (DSN's) Madrid tracking station to confirm that Galileo properly accepted and executed the commands. Starting in September 1991, GSOC will support the cruise science phase of the Galileo mission by tracking the spacecraft for five passes each week, generating Experimenter Data Records, and transmitting noninteractive commands for the fields and particles, low-rate science instruments.

The first combined Ground Data System/Mission Readiness Test for Earth encounter was successfully completed in late October and early November for all these DSN sites. The Test demonstrated the stations' ability to support real-time command and telemetry functions for Earth encounter. In addition, station personnel generated and routed magnetic tapes to the Multimission Imaging Processing Laboratory (for high-rate science) and the Data Records System (for low-rate science) to verify the interfaces.

Four of the planned 10 program sets scheduled for the current software set, C3.2, have been delivered. C3.2 delivery activities have included the successful completion of the acceptance test and delivery reviews for the Experimenter Data Records Generation program set and the Radio Science Closed-Loop Data Validation program set. The Multimission Image Processing System delivery has been delayed pending the fix and retest of problems discovered in acceptance testing. All Project software required for the Earth encounter has been delivered.

—Matt Landano



These images of Venus were obtained by Galileo's SSI at ranges of 1.4 to 2 million miles as the spacecraft receded from Venus. The pictures in the top row were taken about four and five days after closest approach; those in the bottom row were taken about six days out. In these violet-light images, north is at the top and the evening terminator is to the left. The cloud features high in the planet's atmosphere rotate from right to left—from the limb through the noon meridian toward the terminator, traveling all the way around the planet once every four days. The motion can be seen by comparing the last two pictures, taken two hours apart. The other views show entirely different faces of Venus. These photographs are part of the "Venus global circulation" sequence planned by the Imaging Team.

(COMMUNICATION from page 5)

Office Systems Manager for Galileo, commented that "some of the computers are older than the programmers." The new equipment, along with more spares, has increased the reliability of the Subsystem. Software updates for the MCCC Command, Simulation, Operations Control, and Data Records Subsystems were also delivered. In addition to all the changes for launch, MCCC participated in multimission verification tests with the DSN and in Project Ground Data System and DSN Mission Readiness Tests.

More recently, in preparation for Earth encounter, MCCC has made some significant deliveries. The image-processing capability now exists for real-time processing and generating of Experimenter Data Records for the Solid-State Imaging, Near-Infrared Mapping Spectrometer, and Plasma Subsystems—all high-rate data-return systems. Also, a new, multimission optical navigation system will answer Galileo's concerns for support during the flyby of asteroid Gaspra. Scientists plan to check out and demonstrate this system during Earth encounter. New hardware goes with these new software programs. The MCCC Telemetry Subsystem has been fitted with new printer–plotters and improved firmware for interface devices for those printers.

One very innovative part of the MCCC support comes in the form of the very latest in workstations for scientific displays—SANTA2 (Science Analysis Near-Term Activity). An adaptation of the VNESSA (Voyager Neptune Encounter Science Support Activity) system, SANTA2 should enable scientists to analyze the data from Galileo more quickly. At Earth encounter, these interactive displays for real-time data analysis should prove exciting. Still experimental, SANTA2 is supported by the Project on a "best-effort" basis. This is a Space Flight Operations Center (SFOC) pilot program to demonstrate application of SFOC-developed technology.

Although under the cognizance of FPSO/MCCC, Ed Gatz dedicates his time to supporting Galileo. He is assisted by Mel Pinck, Data System Project Engineer, and Jose Coito, Facilities and Operations Project Engineer. More than 250 development and operations people provide around-the-clock support in MCCC for all projects. During Earth encounter, for example, most MCCC personnel will be supporting Galileo in some way, and many will be working different shifts to ensure Galileo receives 24-hour support during this critical period.

While many of the personnel are in the Space Flight Operations Facility, others can be found in offices around the Laboratory, and in the Information Processing Center (IPC) at JPL's Woodbury site. IPC houses the Unisys computers that help generate the spacecraft sequence commands and analyze the spacecraft and navigational data.

In the midst of all this, MCCC is undergoing an end-to-end replacement of all telemetry, command, simulation, and operations control equipment, to be completed by April 1992. The main driver for this replacement for Galileo involves the requirements at Jupiter. At Jupiter, the data rate will jump to 134 kilobits per second. MCCC's present system cannot support such high data rates for months on end. The new equipment can meet Galileo's needs and will be more reliable, more flexible, and faster. Presently, passing the data on to the scientists requires physically taking a tape to MIPL and to Data Records. The new system will include high-speed electronic interfaces, taking advantage of the local area network capabilities on Lab. Eventually, there will be less reliance on paper, and more reliance on individual workstations with built-in plotting capabilities.

Each flight project supported by MCCC has some of its own telemetry equipment and pays for a portion of the MCCC budget. The bulk of MCCC is financed out of the Flight Projects Office. Multimission capability is sized to handle multiple projects simultaneously. For example, MIPL is currently processing both Galileo's playback of Venus data and Earth encounter images, as well as Magellan's mapping of Venus.

(PROJECT MANAGER from page 1)

shortly, Galileo will be on its way to the first spacecraft encounter with an asteroid—Gaspra on October 29, 1991!

The Galileo Flight Team and spacecraft continue to perform beautifully. What great pride and satisfaction there is for all of us in this great enterprise.

—Bill O'Neil

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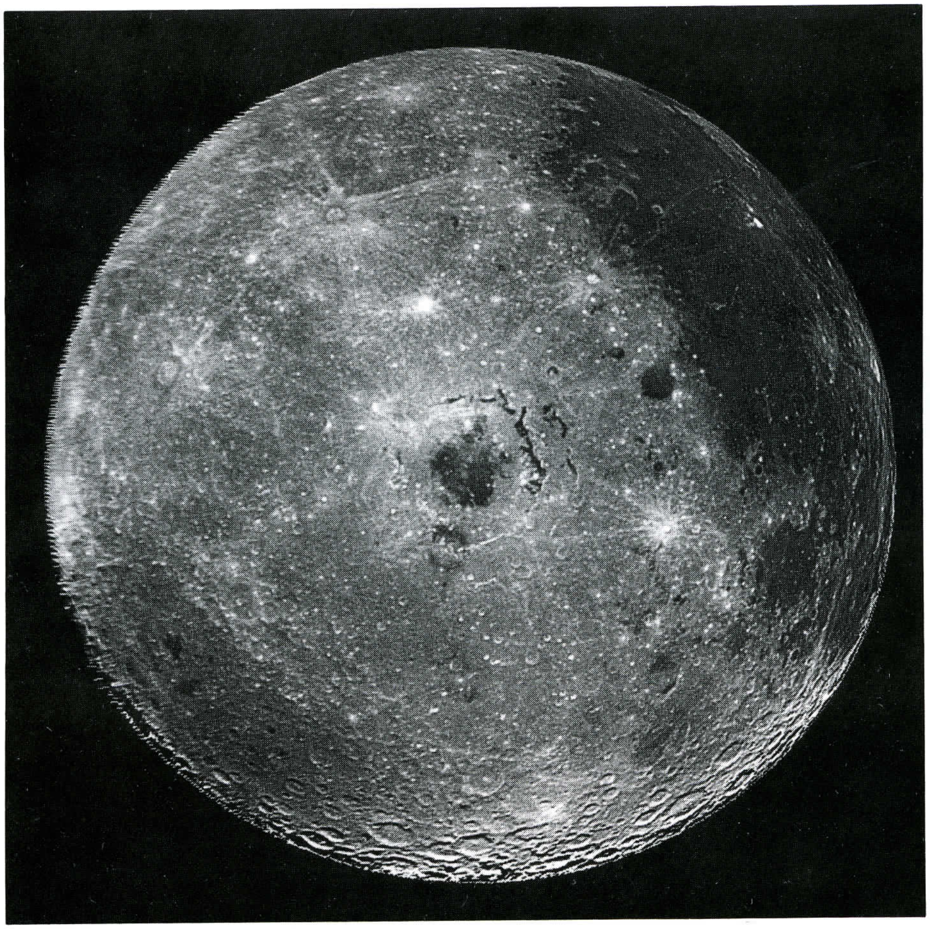
The Galileo Messenger

Issue 27 April 1991

A Closer Look at the Earth and Moon

Galileo's December 8, 1990, flyby of Earth was an outstanding success. The spacecraft's instruments gathered a good deal of information about our planet, its Moon, and their environment in space. Galileo also received a gravity assist that will help send it on its way to Jupiter.



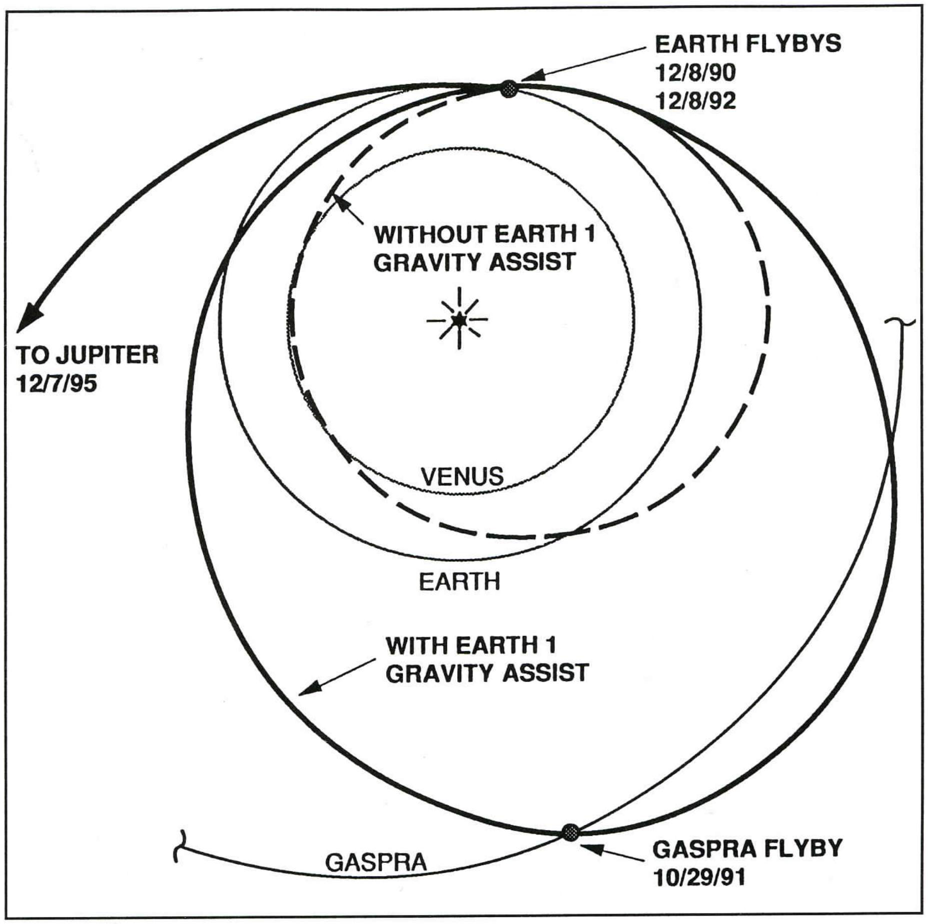
The Galileo spacecraft took this image of the Moon at 9:35 A.M. PST on December 9, 1990, at a range of about 565,000 kilometers (350,000 miles). The concentric, circular Orientale basin, 970 kilometers (600 miles) across, is near the center; the Moon's near side is to the right, the far side to the left. At the upper right is the large, dark Oceanus Procellarum; below it is the smaller Mare Humorum. These features, like the small, dark Mare Orientale in the center of the basin, formed over 3 billion years ago as basaltic lava flows. At the lower left, among the southern cratered highlands of the far side, is the South-Pole–Aitken basin, similar to the Orientale basin, but twice as great in diameter and much older and more degraded by cratering and weathering. The cratered highlands and the maria are covered with scattered bright, young ray craters. (P-37327)

A Second Gravity Assist

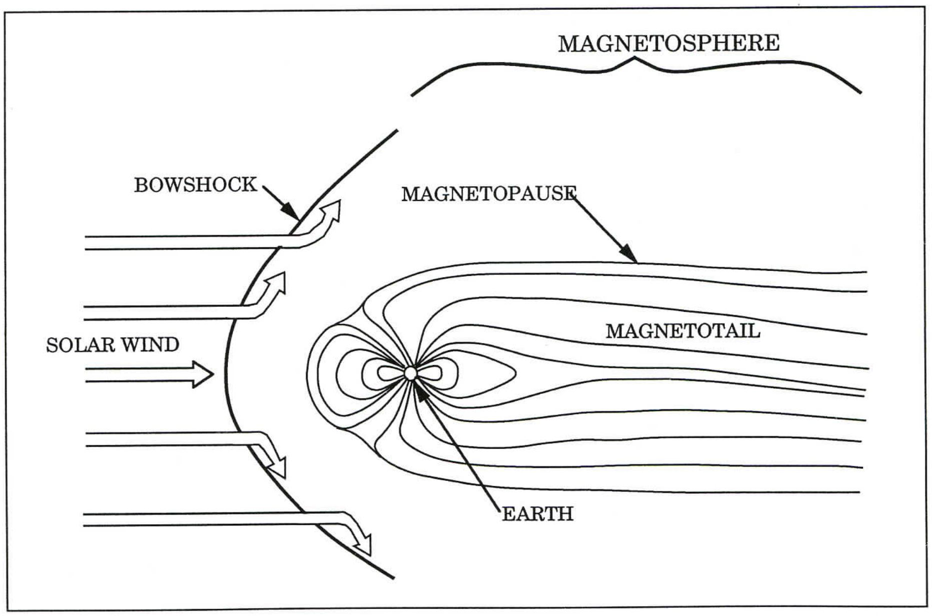
The reason for this flyby was so Galileo could receive a gravity assist. A gravity assist is a technique in which some of a planet's orbital energy is transferred to a spacecraft, bending its path around the planet and increasing its speed around the Sun. Several such maneuvers are necessary to enable Galileo to get to Jupiter. The first gravity assist occurred at Venus in February 1990. After the Venus flyby, six trajectory correction maneuvers (TCMs) put Galileo on the precise flight path for the required gravity assist at Earth. Although the fifth maneuver was extremely accurate, a very small sixth adjustment was made on November 28 to remove remaining trajectory errors.

"Everything has worked superbly, both the spacecraft and the team," noted Project Manager Bill O'Neil. In fact, delivery accuracy was better than 99 percent in aiming point and time of closest approach for both the last two TCMs—TCM 7 and TCM 8. The targeted altitude at Galileo's closest approach to Earth was 952 kilometers (590 miles), and the actual altitude was 960 kilometers (595 miles). The spacecraft was expected to arrive at that point at 12:34:34:00 Pacific Standard Time (PST) and arrived within a half-second — a highly accurate pinpointing.

This gravity assist increased Galileo's speed around the Sun by about 5.2 kilometers per second (or



For Galileo to get to Jupiter, the spacecraft needed gravity assists from Venus and the Earth. These assists changed the spacecraft's velocity—thereby saving the precious onboard propellant. In addition, the assists bent the spacecraft's trajectory, sending it beyond the Earth's orbit and on to Jupiter. Without these gravity assists, Galileo would have simply remained in a roughly circular orbit, touring through the Asteroid Belt and past the Earth and Moon.



The complex interaction between the Earth's magnetic field and the solar wind forms many distinct regions that comprise the magnetosphere.

11,600 miles per hour) and substantially redirected Galileo as required for its flybys of the asteroid Gaspra in October 1991 and Earth in 1992; the second gravity assist from the Earth in 1992 will add an additional 3.71 kilometers per second (8280 miles per hour) to its speed.

A Glimpse at the Earth's Environment in Space

This flyby included a bonus: the chance to study the Earth as Galileo swept by our planet. The first domain that could be studied was the Earth's interplanetary environment: the solar wind and magnetosphere.

The solar wind is a continuous stream of ionized gas (called a plasma) blowing radially outwards from the Sun. It travels at speeds between 200 and 800 kilometers per second, that is, from 450,000 up to almost 2,000,000 miles per hour. This high-speed wind carries the Sun's magnetic field outwards and into the solar system. At the Earth and also at Jupiter, the solar wind is deflected by the planet's magnetic field, forming a magnetosphere. The Earth's magnetosphere protects the planet from the solar wind, deflecting it around the Earth instead of impinging onto the planet's atmosphere. On the Earth's day side, a shock wave forms, much like the shock wave caused by a supersonic aircraft. The night side of the Earth's field is dragged back to form a long tail (over 1000 times longer than the planet's radius). The magnetized plasma that sweeps by the Earth causes magnetic storms and aurorae (sometimes called the northern, and southern, lights).

The plasma that comprises the solar wind is extremely tenuous, with a typical density of only a few particles per cubic centimeter. Plasmas of this sort are difficult to study on Earth. As Galileo's Plasma Detector Principal Investigator Dr. Louis Frank pointed out,

The Galileo spacecraft obtained this image of the Earth at about 6:10 A.M. PST on December 11, 1990, when the spacecraft was about 2.1 million kilometers (1.3 million miles) from the planet. South America is near the center of the picture, and the white, sunlit continent of Antarctica is below. Picturesque weather fronts are visible in the South Atlantic, lower right. This is the first frame of the Galileo Earth-spin movie, a 500-frame time-lapse motion picture showing a 25-hour period of the Earth's rotation and atmospheric dynamics. (P-37330)

though, excellent "laboratories" to study plasmas do exist—in the space near the planet. The Earth's magnetosphere has been studied by spacecraft for 25 years, and although much has been learned, it still holds many of its secrets. The Galileo flyby allowed us to use one of the most sophisticated scientific spacecraft to help further unravel these mysteries, and provided information that will help in the study of Jupiter's magnetosphere.

The Earth's bow shock slows the solar wind down prior to its impinging on the Earth's magnetosphere. The region between the bow shock and the magnetosphere is called the magnetosheath, and it is this region that the Galileo spacecraft first encountered in its December flyby. The Galileo spacecraft approached the Earth from the night side, where the solar wind sweeps the magnetosphere back to form a long tail, called the geotail, surrounded by the magnetosheath. Galileo flew along the magnetosheath and

entered the magnetotail about 560,000 kilometers (348,000 miles) behind the Earth. Fortunately for the scientists involved, the Galileo–Earth encounter took place when the magnetosphere was in a very dynamic state and so, once inside the geotail, the spacecraft detected a number of geomagnetic substorms.

Powered by disturbances in the Earth's field, charged particles traveling along magnetic field lines are scattered into the atmosphere, creating the aurorae and also forming the intense regions of radiation above the Earth called the Van Allen radiation belts. Galileo detected energetic particles throughout the magnetosphere. The spacecraft's observations will help scientists understand the relationship of the aurorae to magnetospheric processes such as magnetic storms.

Another phenomenon observed by Galileo involved the detection of lightning. A lightning stroke emits a broad range of electromagnetic waves, including visible and radio frequencies. Galileo's Plasma Wave experiment can detect the radio frequency emissions as "whistlers," so named because they sound like a whistle decreasing in frequency with time. The reason for this effect is that higher frequencies travel fastest, thus reaching the spacecraft first, followed by the lower frequencies. The result, when played back at corresponding audible frequencies, sounds much like a falling artillery shell. At Galileo's Earth flyby, many lightning whistlers were clearly detected and can be compared with those Galileo may detect at Jupiter, as Voyager's Plasma Wave instrument did in 1979.

A New View of the Moon

Galileo's December flyby also afforded unusual observations of the Moon. In its orbit about the Earth, the Moon always keeps the same face to our planet. Lunar orbiters in the late 1960s and early 1970s studied the Moon's far side, while the Apollo missions primarily studied the Moon's equatorial regions. Apollo 15 made the most extensive observations of the far side. Several of Apollo 15's findings led scientists to surmise that an extremely large basin lay in the far side's southern portion. Thanks to Galileo's images of the material covering this area, scientists now infer that a 1940-kilometer-diameter (1200-mile-diameter) impact basin exists—a basin that, on Earth, would extend from Mexico to Canada and from Los Angeles to Kansas City. This impact structure was probably caused by a 160-kilometer-diameter (100-mile-diameter) meteor that punched through to the Moon's mantle. One scientist described the impact "like a small state coming at you from space." Such a large impact would have caused large perturbations and may have reoriented the Moon's axis. Certainly the Moon's mass would have been redistributed.

The spacecraft's images also show evidence of a mare underlying the ejecta from the later impact that created the Orientale basin, pushing back the estimate of lunar volcanism by 100 million years, to 4 billion years ago.

While we have studied the Moon extensively in the past, Galileo discovered several new things. Galileo confirmed the earlier hypotheses from Apollo 15's analyses of altimetry and composition of the far side and the existence of an impact basin in the south polar region. Galileo's findings clarified characteristics of unexplored regions, improved our coordinates of lunar features, and enabled us to see entirely new parts of Moon. Much of this mapping covers "territory virtually unexplored by modern sensors," noted Project Scientist Torrence Johnson.

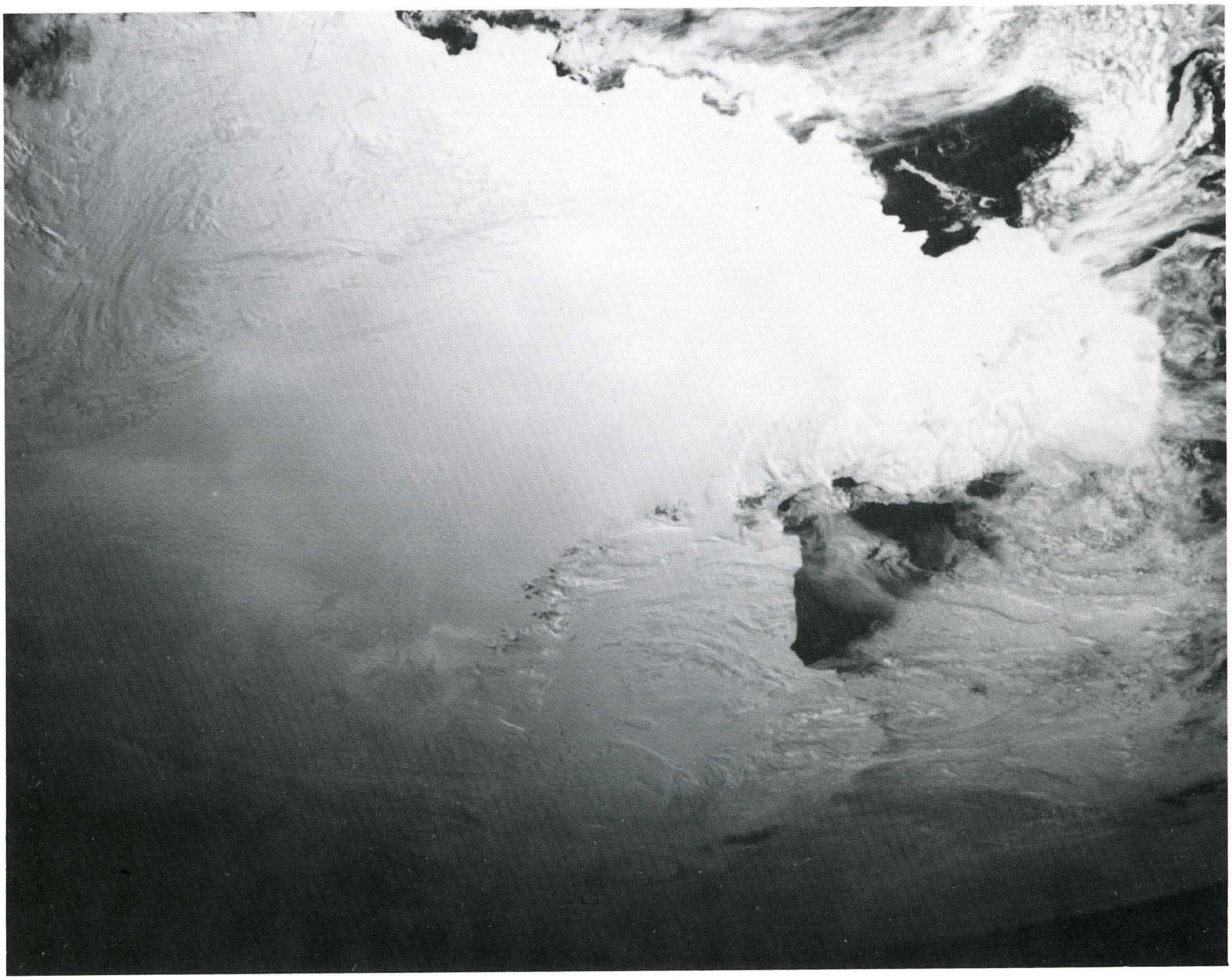
A Glance at the Earth Through New Senses

While scientists have always studied the Earth, Galileo's unique trajectory and host of instruments allowed new observations to be made of our home planet. Some of these new investigations yielded a better understanding of aurorae, new insights into the ozone hole and its causes, a high-quality movie of the spinning Earth, and multispectral imaging and ground truth studies of Australia.

The dynamic movie of the Earth's rotation was taken over a 25-hour period as Galileo retreated from the Earth. Taken from a vantage point below the equator, the movie centers on the southern hemisphere, although the frames extend as far north as Florida and the Persian Gulf. The movie gives scientists a unique view of global weather patterns.

Observations of very high clouds in the mesosphere were made by the NIMS. Located above the stratosphere, the mesosphere is the coldest part of the atmosphere (130 K) and plays a significant role in the ozone chemistry cycle. Such high mesospheric clouds in northern and southern latitudes have been seen only since 1885. These clouds are indirectly caused by increasing amounts of methane released from industry. The methane, in turn, causes an increase in the warm air that flows into the polar regions. Coupled with natural springtime heating, the warm air increases the temperature dramatically and the ice pack melts more quickly, releasing more water vapor into the atmosphere. The water vapor, now in the form of mesospheric clouds, reacts with the ozone and breaks it apart, thereby depleting the ozone and creating an ozone hole.

Although these clouds are occasionally seen in September and October and are rarely seen as late as December, Galileo's instruments revealed several clouds. Such an anomaly may indicate a



This picture of Antarctica is a mosaic of 40 images obtained by the Galileo spacecraft's camera using several filters. When the images were taken several hours after Galileo's Earth flyby on December 8, 1990, the spacecraft was about 200,000 kilometers (125,000 miles) from the Earth.

Surrounding the icy continent, the black of three oceans may be seen: the Pacific to the lower right, the Indian to the upper right, and a small section of the Atlantic at the upper left. Nearly the entire continent was sunlit at the time, just two weeks before the Antarctic midsummer. The South Pole is left of center; the arc of dark spots extending below there and to the right is the Transantarctic Mountain Range. To the right of these mountains is the vast Ross Ice Shelf and its sharp border with the dark waters of the Ross Sea, merging into the South Pacific. The faint line along the curved limb of the Earth, at the bottom, marks our planet's atmosphere. (P-37593)

change in the ozone population. A fundamental problem in ozone depletion centers on the fact that since ozone helps shield the Earth's surface from the Sun's heat, a decrease in ozone yields an increase in polar heating. In turn, this creates more mesospheric clouds, destroying more ozone. To create good models of how ozone depletion occurs, scientists need highly accurate data regarding the amount of mesospheric water. This had always been a missing factor in the equation, but Galileo's observations supplied that vital information.

Due to the fact that Galileo encountered Venus in February 1990, Project Manager Bill O'Neil has characterized the spacecraft as "the first confirmed interplanetary visitor to Earth." Encountering the Earth as a planet for the first time enabled scientists to evaluate their methods of interpreting data with a critical eye by comparing what they could surmise from Galileo's data with what they actually knew.

Scientists were able to verify the Earth's mass, diameter, composition, magnetic field, aurorae, and atmospheric composition.

One objective note of interest was the detection of a high oxygen level combined with a low carbon dioxide level. The proportions of these gases were not at equilibrium, indicating an additional driving factor—could there be life? Interestingly enough, Galileo's observations could not objectively prove that life exists on Earth. Indications were strong that life

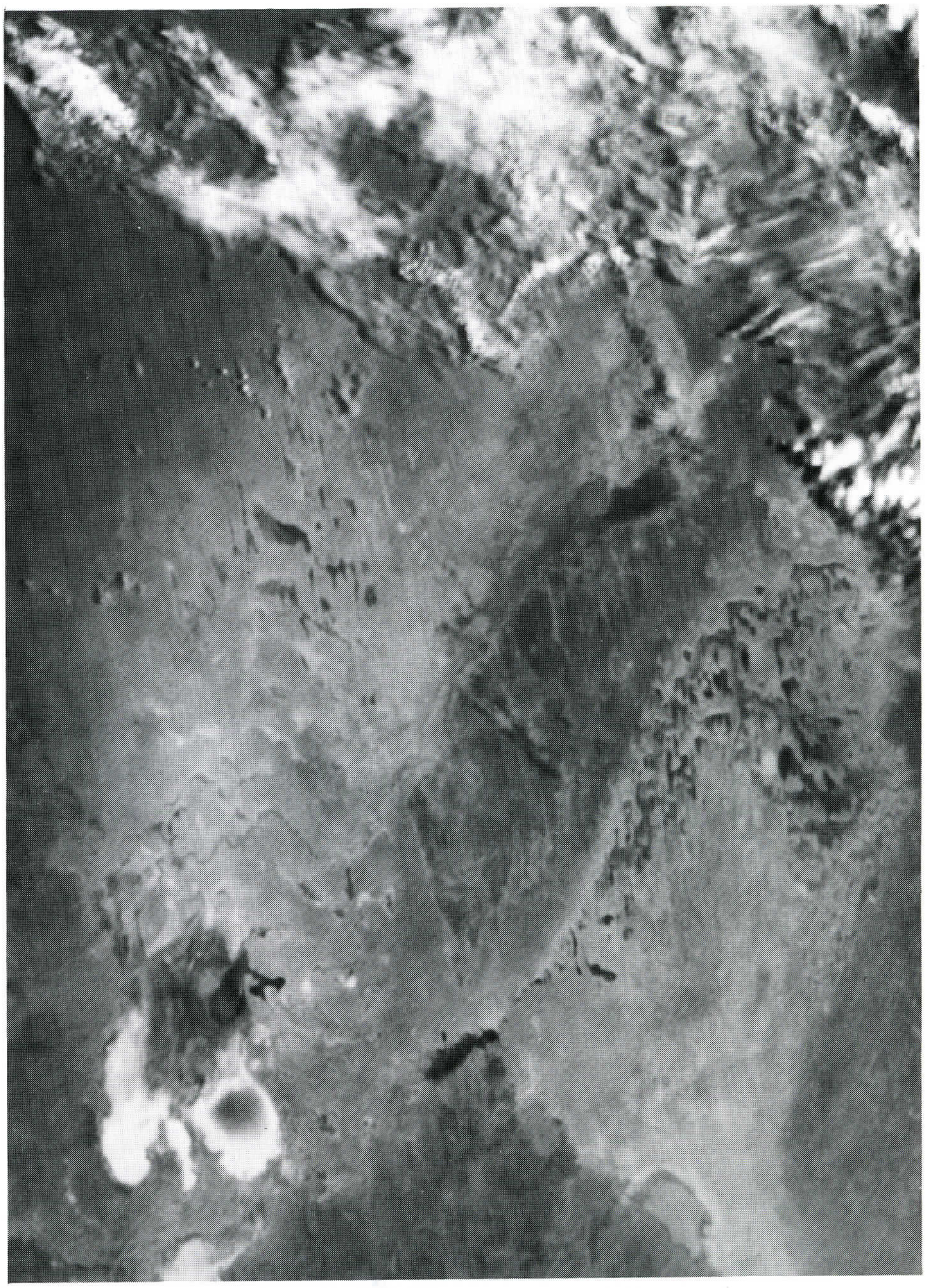
did exist—some unusual radio waves and the levels of oxygen, carbon dioxide, methane, and nitrous oxide all pointed to biological life. To be fair, Galileo's instruments were not constructed to detect civilization on the Earth. Because of Galileo's trajectory and distance at the Earth flyby, its imaging resolution was 1 kilometer (0.62 mile). A resolution of 100 meters (330 feet) would have been necessary to image human constructions. However, at its best, Galileo will achieve a 50-meter (165-foot) resolution on Jupiter's satellites.

A Shakedown Cruise

One of the flyby's additional benefits was the chance to thoroughly check out all the instruments and operations. "Every time we turn on an instrument . . .," Clayne Yeates, Science and Mission Design Manager, said, "we're really learning how to operate these instruments. It's been invaluable for us to collect this data." This flyby has been a good shakedown of the spacecraft and ground operations in preparation for operations at Jupiter.

Using the spacecraft's performance of the 7000 commands given and the 58 billion bits of data collected during the encounter, Project engineers now have a better understanding of how to finely control the scan platform and operate the science instruments. The Solid-State Imaging System, Galileo's "camera," was particularly tested, delivering 2,675 frames during the encounter.

"This encounter was a valuable experience of working with the instruments and the teams. We had seven days of detailed observations of the Earth and Moon," Project Scientist Torrence Johnson reflected. "This was just a small preview of what Galileo will do in 1995 on every one of its orbits of Jupiter."



The Galileo spacecraft obtained this image of the Simpson Desert in Australia at about 2:30 P.M. PST on December 8, 1990, at a range of more than 56,500 kilometers (35,000 miles). The area shown, about 450 by 550 kilometers (280 by 340 miles), is southeast of Alice Springs. At the lower left is Lake Eyre, a salt lake below sea level and subject to seasonal water-level fluctuations; when this image was acquired, the lake was nearly dry. At the lower right is Lake Blanche. Fields of linear sand dunes stretch north and east of Lake Eyre, shaped by prevailing winds from the south and showing the various sources and ages of their sands. (P-37331)

Editor's Note: This issue is a special edition covering the Earth–Moon encounter. The Messenger will return to its usual format next issue.

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The Galileo Messenger

Issue 28 August 1991

From the Project Manager

As most everyone now knows, when the High-Gain Antenna (HGA) was commanded to unfurl last April, several of its ribs stuck to the tower. Ever since, the Project has been working very hard to determine what is holding those ribs to the tower and what actions to take to free them. (See "Unfurling the HGA's Enigma.")

The probable scenario is that the rib-locating pins that brace a rib when it is clamped to the tower are frictionally bound in their receptacles. This binding friction is due to a loss of lubrication and an anomalously high normal force between the pinhead and the receptacle due to pin-pair misalignment ("preload"), and then digging the pinhead into the receptacle's lower surface with the deployment bending moment. The lubrication was most likely worn off in the numerous road trips between Florida and California.

By shrinking the antenna tower (using the cooling turns), we hope to reduce the "digging force" to the point where the deployment strain energy now concentrated in the few stuck ribs will overcome the preload and pop the ribs out. The July and August cooling turns did not get the tower cold enough. We are planning a December turn that will get it colder. If this does not succeed, we will alternately heat and cool (cycle) the tower in the fall of 1992, when Galileo is near 1 AU to "walk" the pins out. I am

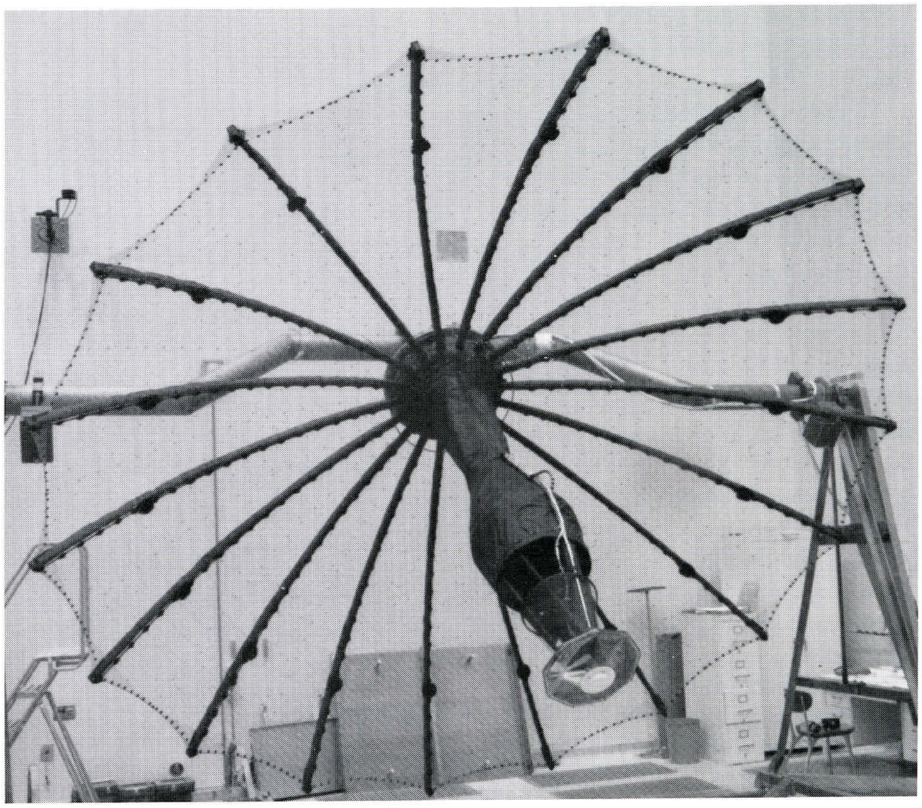
— see page 4

Unfurling the HGA's Enigma

On April 11, Galileo's High-Gain Antenna (HGA) should have deployed. However, signals received from the spacecraft indicated that the antenna only partially deployed, leading to the current assumption that three of the antenna's ribs are stuck in the stowed (or closed) position, while the others are partially open. The Project has performed three spacecraft turns, the first one to warm, then the next two to cool the antenna. The antenna remains partially deployed. The last activity was a cooling turn performed August 13 through 15.

The main difficulty in accurately deducing the actual configuration of the antenna lies in the sparse amount of data available from the spacecraft. The three primary pieces of information available are derived from the motor current, from wobble identification, which tells if the antenna is deployed evenly, and from the Sun gate sensor, which is currently obscured by one of the antenna's ribs.

An HGA Deployment Anomaly Team was formed on April 11. It was chartered to develop likely failure scenarios and credible



The high-gain antenna is shown in its full deployment during pre-flight testing.

explanations for the partial deployment. Also, the Team was to assess the risks and develop supporting requirements and plans for recommended actions. The Anomaly Team consists of mechanical, electrical, thermal and materials design, reliability, and flight operations personnel from JPL and contractor personnel from Harris Corporation, the builder of the HGA.

A primary consideration in any attempt to unfurl the antenna is the Project's requirement that any spacecraft action must be safe and must not preclude subsequent deployment.

The Available Data

The HGA deploy sequence was executed on April 11, as planned, by issuing commands to turn on the deployment motors. The motors ran at higher than predicted power levels for nearly the full sequenced 8-minute period. The microswitch-controlled motor shutdown expected about 2.5 minutes after the motors were powered on did not occur. Instead, in the first 58 seconds, motor current increased to a value consistent with full available stall torque.

Preliminary analysis of the data stemming from the attempted HGA deployment, including power consumption and attitude dynamics information, suggested that the HGA was partially and asymmetrically deployed. The Sun gate sensor became partially obscured during the deployment attempt and, based on spacecraft–Sun orbital geometry, it could be concluded that antenna rib #2 was deployed 35° from the stowed position. Attitude and Articulation Control Subsystem (AACS) wobble data indicated an asymmetric condition with the position of rib #2 being at, or very near, the maximum rib deploy position. This inferred antenna geometry was corroborated by analysis of the motor drive system configuration at stall.

Subsequent to the HGA warming maneuver, AACS data and radio frequency and antenna pattern data were reviewed. Analysis of the AACS wobble test data indicated that the wobble angles before and after the HGA heating turn were nearly identical—3.47 and 3.52 milliradians, respectively. Wobble changes as small as 0.1 milliradian can be discerned. If the HGA were symmetrically deployed, the expected post-turn wobble angle would have been near 1 milliradian.

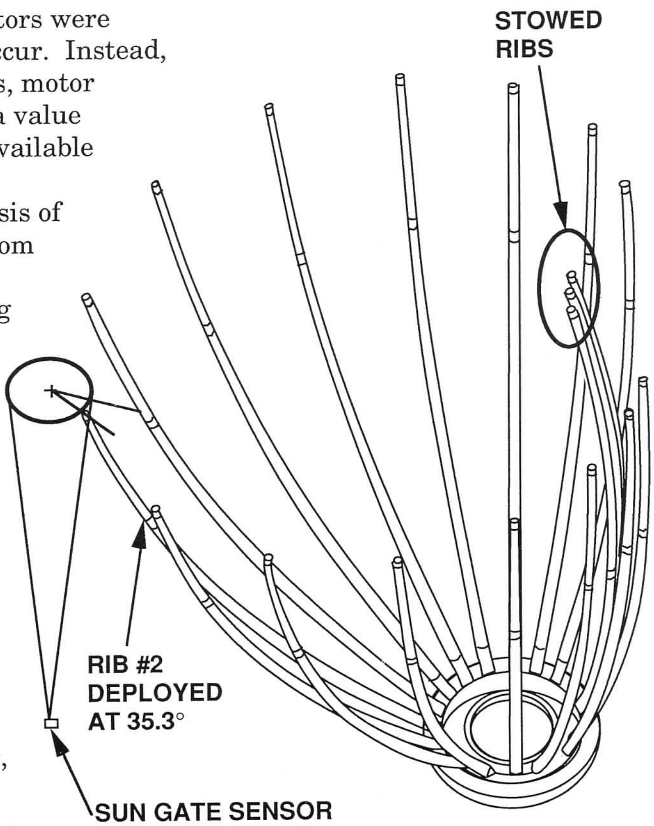
Analysis History

By April 30, the Anomaly Team initially speculated that "one or more ribs are probably restrained in the stow position, resulting in an asymmetrical partial deployment." At that time, this was the most probable scenario, but the cause was unclear.

To verify this scenario, the Team began a comprehensive test and analysis program, including reviewing all videos and still pictures of the Galileo deployment from the Shuttle to ascertain the status of the antenna and the tip shade, continuing detailed analysis of the telemetry data, and reviewing all procedures associated with the Central Release Mechanism. In addition, the Team was evaluating the thermal differential expansion of the entire antenna tower and the feasibility of a rib tip restraint pin getting stuck, reviewing the effects of shock and vibration loads on the ribs, and testing the ball screw in a thermal vacuum.

Some of the first corrective actions considered were commanding another release of the central release mechanism (CRM), altering the thermal environment of the antenna (heating and cooling and thermal cycling), shaking the spacecraft to create a force, and turning the deployment motor on again to try to get some back drive. However, since the deployment motor would increase the friction load on the alignment pins of stuck ribs, the Team agreed that such a turn-on should not be attempted until all other efforts to free the ribs have been exhausted.

The initial scenario involved three to five stuck ribs, but now it is believed three stuck ribs are restrained in the stow position and that additional ribs may have been involved initially. No damage has occurred to the dual-drive motor/ball screw, and full capability is likely if the ribs can be opened; nor has structural failure occurred to any hardware component in the motor drive subassembly. Efforts should continue to perform an antenna tower cooling turn in an attempt to free the ribs. These conclusions are based on the close comparison achieved between



The current scenario is that three of the antenna's 18 ribs are stuck in the stowed position. One piece of available data that confirms this theory is that the Sun gate sensor is obscured by rib #2.

flight data and modeling data profiles and a confirming scenario demonstration deployment with the spare antenna.

Warming Turn

Originally, the Anomaly Team thought that heating the antenna might free the stuck ribs. Therefore, a warming turn was performed. On May 20, the spacecraft was turned about 38.2° (the largest turn to date) to provide solar heating of the HGA tower; the spacecraft angle off-Sun after the turn was about 43°. Spacecraft performance during the turn was excellent and, generally, near predicted levels, achieving the desired turn attitude within 4 milliradians. This warming turn, unfortunately, did not release the stuck ribs.

July Cooling Turn

The first HGA cooling turn was performed on July 10 at a solar distance of 1.84 AU. The turn pointed the spacecraft's –Z axis about 165° from the Sun to shade the entire HGA. Spacecraft performance throughout the turn was normal; the turn angle achieved was about 9 milliradians from the expected 165°.

Having reached attitude, the spacecraft was then commanded to the all-spin mode for the duration of the nominally planned 32-hour "cold soak." A "quick look" review of the actual temperatures indicated that all were within the allowable temperature limits or that the limits had been waived specifically for the turn. After 24 hours at attitude, the HGA element temperatures reached very near steady-state values. The HGA final temperatures achieved were compatible with those used in rib-release analyses.

Following the spacecraft's return to the Sun-pointed attitude after the 32-hour HGA cold-soak activity, telemetry indicated that the Probe shelf temperatures were still increasing and, based on projections, could reach or exceed the pre-turn agreed-to limit of 22.5° C. Immediately prior to the start of the return to Sun point, Probe shelf temperatures had reached about 16° C. Nearly 24 hours later, Probe temperatures had gone slightly above 21° C due to thermal soak back. The shelf temperatures then stabilized. By July 15, Probe shelf temperatures had dropped to near 16° C and were continuing a downward trend.

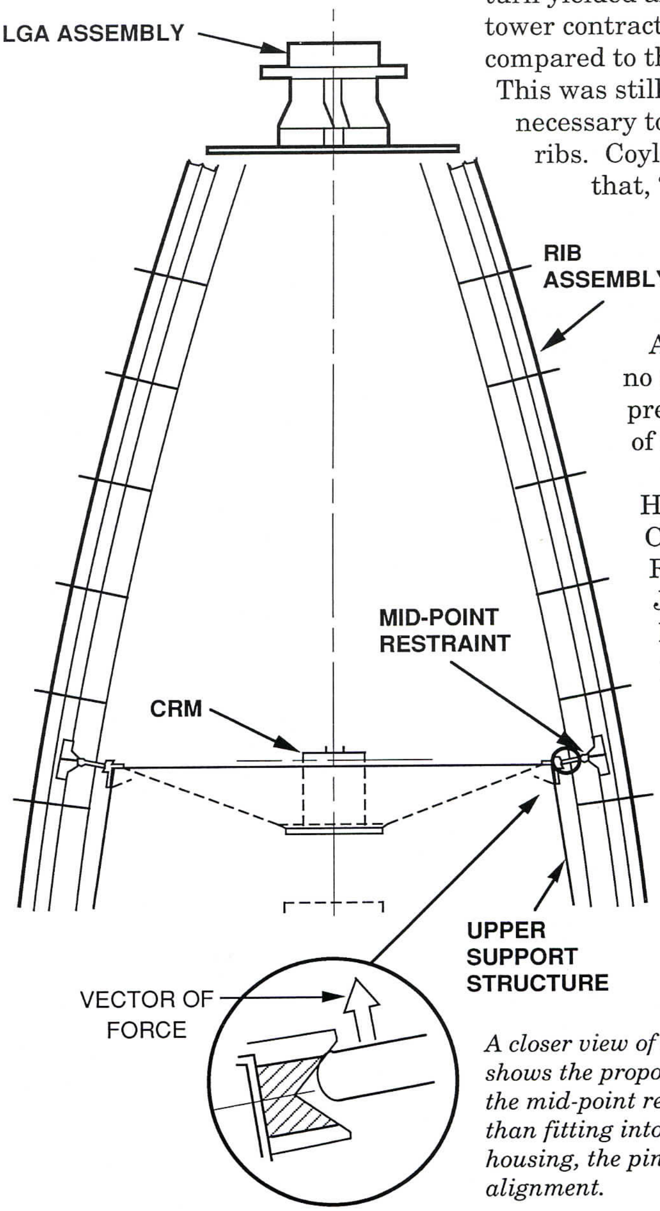
This cooling turn did not release the stuck ribs. "We have to get colder, and we know how to do that," said Bill O'Neil, Project Manager. "We can get it cold enough so the frictional forces can no longer hold the ribs in. This cooling turn was flawlessly executed and represents a tremendous improvement in our knowledge of cooling for the next turn."

August Cooling Turn

A second HGA cooling turn occurred on August 13 at a solar distance of about 1.98 AU. This turn incorporated several changes to cool the antenna, including lowering the spacecraft bus power consumption and turning off the Plasma Wave Subsystem magnetic field sensor heater located on the antenna tower. The time at the cooling attitude was increased from 32 to 50 hours.

Gary Coyle, Galileo Antenna Task Manager, said, "This cooling turn yielded an additional antenna tower contraction of 0.004 inch compared to the first attempt." This was still short of what was necessary to loosen the stuck ribs. Coyle went on to state that, "The wobble identification, on August 19, and the Sun gate sensor check, on August 20, showed no change from the previous configuration of the HGA."

For this turn, Hughes Aerospace Corporation, Ames Research Center, and JPL negotiated a Probe upper temperature limit of 33° C; this new limit represents a thermal constraint relaxation of about 11° C from the July turn. "The



A closer view of the stowed antenna shows the proposed misalignment of the mid-point restraint pins. Rather than fitting into the center of the housing, the pins were tilted out of alignment.

Probe's temperature during this cooling turn reached 31° C," noted Ron Reeve, Galileo Temperature Control Cognizant Engineer. "We believe the Probe remains in good shape."

The Plasma Wave Subsystem (PWS), on the other hand, endured temperatures that went, literally, off its scale. A reconstruction of the temperature readings suggests that the PWS's search coil preamplifier reached a temperature of –165° C. It had been qualified in pre-flight testing for a minimum temperature of –35° C.

The preamplifier is currently drawing a current, which may indicate that everything is in working order. A more detailed analysis of the effect of such cold temperatures on the instrument will be conducted at the end of September, when the PWS is next scheduled to send back data.

Project Manager (Cont'd)

determined and confident we will deploy the HGA. NASA Headquarters has just reiterated its full support of our approach and its commitment to the complete success of Galileo.

Except for the HGA, the Galileo spacecraft has performed superbly in now nearly two years of flight—it has been to Venus, back to Earth, and now beyond 2 AU, entering the asteroid belt. The Flight Team is outstanding and they really showed their stuff in flawlessly performing the highly nonstandard, very complicated HGA cooling turns.

For the next two months, the Flight Team will focus on Gaspra. Our October 29 Gaspra encounter without the HGA will be very little degraded—the best images about 20% less in resolution than originally planned. However, we will have to wait until the HGA is unfurled or the next Earth flyby at the latest to retrieve the Gaspra data from the tape recorder.

—Bill O'Neil

Galileo Status: Up to Date

During the past six months, the Project's understanding of the spacecraft has increased dramatically. Through the routine operations and, particularly, through the anomalous events involving the High-Gain Antenna and the Command Data Subsystem, engineers are honing their skills in operating and analyzing Galileo's signals.

The spacecraft reached perihelion at 0.9 astronomical units (AU) on January 11; thermal profiles were near the expected levels and no anomalies were observed. Now receding from the Sun, the spacecraft travels toward an encounter with the asteroid Gaspra (at about 2.1 AU) in late October 1991, prior to Galileo's planned second Earth flyby (at 0.98 AU) in December 1992.

The Galileo status given here covers the period from November 16, 1990, to August 1, 1991. Throughout this period, a variety of spacecraft activities took place, including turn activities, maneuvers, retropropulsion module flushings, Sun acquisitions, and memory readouts.

The Spacecraft

During this time, the spacecraft has performed very well. There were 17 SITURNs (turn activities) performed. The November 16, 1990, SITURN, about 22°, was the largest to date and resulted in the spacecraft leading the Sun by about 12.5°. This SITURN used the P thrusters, as did nearly all of the others in this interval. However, the January 7 SITURN was performed using the unbalanced turn capability with the Z thrusters. This was the first time an unbalanced turn had been performed. The unbalanced turn demonstrated this functional capability prior to its planned use for the Trajectory Correction Maneuver (TCM-9B) in March.

The spacecraft executed the TCM-7, TCM-8, TCM-9A, TCM-9B, and TCM-10 maneuvers very well. The July 10 TCM-10 was the first Galileo turn-burn-turn maneuver and the first maneuver targeted to the Gaspra flyby aim point. Analysis of the navigational data indicated about a 0.4% underburn.

*Galileo Mission Summary**

Distance From the Earth	221,822,460 kilometers (137,529,930 miles)
Distance From the Sun	290,604,960 kilometers (180,175,080 miles) (1.93 AU)
Distance From Gaspra	65,545,110 kilometers (40,637,970 miles)
Round-Trip Light Time	24 minutes, 26 seconds
Heliocentric Speed	18.92 kilometers per second (42,230 miles per hour)
Spin Configuration	Dual spin—cruise mode
Spacecraft Spin Rate	3.15 revolutions per minute
Spacecraft–Sun Angle	~2.5 ± 0.3° off Sun (lagging)
Downlink Telemetry Rate	40 bits per second (low rate) using Low-Gain Antenna 1
General Thermal Control	All temperatures within acceptable range
Powered Science Instruments	Energetic Particles Detector, Dust Detector Subsystem, Solid-State Imaging Subsystem, and Heavy Ion Counter
RTG Power Output	536 watts
Real-Time Commands Sent	5482 commands

**All information is current as of August 1, 1991.*

Galileo engineers have conducted many tests to help refine their theories about the current configuration of the HGA. Here, the four-stuck-rib scenario is recreated so testing can be conducted on this spare antenna.

Fourteen retropropulsion module (RPM) 10-newton thruster maintenance activities took place. In most instances, only ten of the twelve 10-newton thrusters were "flushed" during these exercises. The P-thrusters generally were not flushed since they have been in use for all the Sun acquisition activities. These Sun acquisitions were executed, as planned, to maintain a thermally safe Sun-pointed attitude. Following each Sun acquisition activity, the star buffer memory readout was performed. These readouts provide valuable star intensity information data, which is used to update the attitude control star catalog.

Routine memory readouts were also performed for several science instruments. These instruments gather data and the information is normally read out at periodic intervals every few weeks. This is the case, particularly, for the Extreme Ultraviolet Spectrometer (EUV), Dust Detector Subsystem (DDS), and Magnetometer (MAG) instruments. A special EUV memory readout was accomplished on November 10, 1990, in response to an observed anomaly. The readout revealed that two bits of a single byte were corrupted. The memory corruption was similar to that observed during the December 1989 four-day science check-out, but the new corruption was at a different memory location. The latest anomaly was recreated and verified on the EUV simulator at the University of Colorado. The cause of these memory corruptions is being investigated vigorously. Commands were sent on November 13 to "patch" the corrupted memory location, and proper operation was restored.

As a result of Magellan Command Data Subsystem (CDS) memory failure and Galileo pre-launch memory failure predictions, the Project has been concerned about possible memory failures in the CDS. The CDS' memory is composed of two strings ("A" and "B") that control its functions. Therefore, CDS "A" and "B" memory copy activities were performed on January 8 and 17, respectively. These activities demonstrated the first in-flight use of the CDS copy capability. For these copy activities, the memory contents of the CDS "A" and "B" elements were copied from the prime memory into the extended memory. Spot-check memory readouts indicated no parity errors or anomalies. This copying will reduce the time to recover from a future possible chip or location failure.

On March 26, spacecraft safing was automatically entered in response to a CDS "B" string down condition caused by a CDS "B" reset spurious transient signal. Similar situations occurred on May 2 and July 19, which resulted in a CDS "A" string down condition. The Flight Team was able to isolate the anomaly, recreate the spacecraft anomaly and response on the test bed, and return the CDS to full operation in about a week. During a spacecraft nontracking period between July 4 and 8, the twelfth anomalous transient CDS critical controller 2A power-on reset telemetry indication occurred. As in all prior occurrences, the CDS functional operation was not impaired and, subsequently, the telemetry indicator was reset by ground controllers.

Another ongoing anomaly investigation involves the AC/DC bus imbalance measurements. As of August 1, the AC bus imbalance measurement read 45.6 volts, with the largest AC fluctuation since

last fall being only 4 Data Numbers (DNs). The DC measurement now reads 14.9 volts. The DC fluctuation is much larger than the AC one, with the greatest fluctuation of 160 DN (ranging from 8.8 to 18 volts) occurring on February 25. To provide greater visibility into the AC/DC bus imbalance anomaly, commands were sent on February 1, allowing a selected set of measurements (voltages, currents, and temperatures) to be sampled as a group every 20 seconds rather than every 240 seconds, as had previously been done. The likely cause of this anomaly, the CDS bus reset anomalies, and the CDS critical controller 2A power-on-reset telemetry anomalies is slip-ring brush debris in the spin-bearing assembly forming momentary conductive paths between adjacent signals.

A variety of activities occurred relating to the partial deployment of the High-Gain Antenna. These activities are covered in more detail in "Unfurling the HGA's Enigma" in this issue.

On April 11, deployment of the High-Gain Antenna was attempted. The attempt resulted in the antenna being partially and asymmetrically deployed. Since the HGA is needed to return high-rate telemetry data from large distances, the low-gain antennas are currently being used for low-rate data return. However, while the spacecraft was near Earth in December 1990, telemetry data rates as high as 134.4 kbps over the low-gain antenna were transmitted and processed by the Ground Data System (GDS). This data rate is the spacecraft's maximum designed data rate and this was the first in-flight use of this rate. The data were successfully received and processed by the GDS.

The only antennas currently used for communications are the low-gain antennas (LGAs). An LGA antenna switch event (LGA-2 to LGA-1) was successfully performed on January 31. No further use of the LGA-2 was planned. However, because of the HGA deployment anomaly, several LGA switches have been performed in support of the cooling turns.

The Probe

A Probe checkout was successfully performed on December 4, 1990. All power consumption and thermal profiles were near predicted levels. Preliminary analysis indicated Probe operation was normal and no unexpected Probe events were observed; the Probe health is excellent. The Probe's Relay Link ground system program set successfully completed its acceptance test and delivery reviews and was delivered to the Project on July 29.

Phase II MOS Design

The Phase II Mission Operations System (MOS) Design Verification Review was completed on November 9, 1990. The Galileo Review Board concurred with the MOS design changes resulting from the Venus–Earth–Earth gravity assist (VEEGA) trajectory and preliminary staffing profiles for the period from launch plus 21 months through the end of the mission. The objective was to develop a realistic work plan considering MOS design items and the continuing operational support requirements. Each of the items was discussed, scheduled, and assigned to a specific office or team for work.

Ground Data Subsystem

The German Space Operations Center (GSOC) has reported that installation of upgraded telemetry and command computer hardware has been completed and regression testing of the software and complete system has begun. GSOC is in the process of testing German ground data system capabilities in preparation for its planned support of Galileo cruise science operations, which were scheduled to begin in September 1991, but which have been delayed due to the HGA anomaly.

The Project Change Board approved the Flight Projects Support Office Multimission Image Processing Subsystem delivery for supporting Galileo. The new delivery provides a number of corrections and performance improvements needed for supporting the Gaspra encounter.

Other software delivery activities have been completed, including modifications and corrections to programs needed to support the Gaspra encounter.

The October 1, 1991 software development and delivery activities have begun. A total of 23 program sets are currently planned for delivery. The deliveries will provide updates to capabilities necessary to support uplink design activities at the second Earth encounter, final tour design activities, and Gaspra non-real-time downlink support enhancements.

The Space Flight Operations Center Phase I hardware installation started with the placement of the first workstation in the Galileo Mission Support Area (MSA). A total of 12 workstations will be installed in the MSA as part of the Phase I installation scheduled for completion by mid-August. The Phase I hardware will be used for familiarization and early testing prior to the formal delivery of the Galileo software next year.

Sequence Development

The Project reviewed and approved the final sequence and command products for several control sequences. These sequences covered spacecraft activities from: December 17, 1990, to February 18, 1991 (VE-12); February 18 to April 29 (VE-14); April 29 to July 22 (EE-1); and September 3 to October 28 (EE-2 prime). In addition, because of the CDS bus reset anomalies, numerous real-time mini-sequences have been developed to carry out the spacecraft's required engineering and health- and safety-related

— see page 8

Tracking the Sequence of the SROP

Between the domains of the Project Office, which decides how Galileo's entire mission will proceed, and those of the Mission Design and Sequence Teams, which detail the spacecraft's events to a millisecond, lies the realm of the Science Requirements and Operations Planning Team (SROP).

From the Galileo science investigators and their JPL colleagues, the Science Coordinators, the SROP Team collects the information necessary to create scientific sequences, supervising the integration of the many observation requests into a single event sequence.

Team Chief Jim Dunne leads the SROP's three sequence integrators and three technical support people. Karen Buxbaum (Deputy Team Chief), Dave Bliss, and Paul Schulte, the sequence integrators, orchestrate the resolution of conflicts among the various experiment observation requests and act as contacts with the Mission Design, Orbiter Engineering, Navigation, Mission Control, and Sequence Teams, and with the Science Coordinators. Three technical support people—Valerie Henderson (Technical Support Lead), Julio Osornia, and Alicia Allbaugh—assist the Science Coordinators in generating the sequence products.

These seven people comprise the SROP staff and are the focus for the science sequence inputs, acting as the executive team for the science planning process. An additional 20 people on the science teams act as Science Coordinators, interpreting scientists' needs and negotiating for the best time in the sequence for their instrument.

The larger SROP includes the SROP staff, the Principal Investigators, the Co-Investigators, and the Science Coordinators. This group develops the scientific guidelines and detailed contents for each activity plan. The SROP staff and the Science Coordinators then convert the decisions from these meetings to a level usable by the Mission Design Team (MDT) and Sequence Team. The SROP develops Galileo's science sequencing plans first at the "activity" level, where the events are timed to about a minute, and then at the "plan" level, where two-thirds of a second makes a difference.

The full SROP's deliberations revolve around Galileo's scientific encounters, including the asteroid Gaspra flyby. "Scientific content is **always** determined by the investigators," Jim Dunne emphasized. "The Science Coordinators are able to adequately represent the Investigators in the detailed sequence development because they know, by long-term interaction with the scientists, what the scientists want to accomplish."

The Science Coordinators put together science sequences using the SROP-developed OASIS program. OASIS merges the files from all the coordinators with the MDT-generated "skeleton" plan. (The skeleton plan contains the necessary engineering and navigation activities for the planned period, provided by the Orbiter Engineering and Navigation Teams, and the Deep Space Network tracking support profile, provided by the Mission Control Team.) OASIS also identifies and consolidates science conflicts into a single "conflict file."

Next, the SROP sequence integrator works with the Science Coordinators to resolve the conflicts either by changing the timing of an event or by sharing resources among several instruments. Such sharing often allows two instruments to occupy the same observing period by quickly switching from one instrument to the other. Each conflict must be carefully negotiated by the Science Coordinators, the sequence integrator, and the cognizant PIs.

The SROP members then document these agreements and generate an activity plan for final review by the Investigators in a meeting of the full SROP. By the time the activity plan is completed and published by the MDT, the SROP has worked with just about every flight team on the Galileo Project.

In addition to science sequence design, the full SROP has also deliberated on such things as when

The members of the SROP team include, from left, back row, Paul Schulte, Dave Bliss, Team Chief Jim Dunne, and Alicia Allbaugh and front row, Valerie Henderson, Julio Osornia and Deputy Team Leader Karen Buxbaum.

Galileo should arrive at Jupiter and delivers recommendations to the Project Science Group, the senior science advisory group under the direction of Torrence Johnson, the Galileo Project Scientist. In the case of the Jupiter arrival date, many factors influenced this decision—for trajectory reasons, Galileo needed to come close to Io; for the magnetic fields instruments, Galileo had to traverse the Io torus; to deliver the Probe into the Jovian atmosphere, Galileo's trajectory had to pass through a certain point; to make darkside measurements of Jupiter, Galileo needed to pass on the far side of the planet; and to retrieve any data at all, the SROP had to accommodate the allocation schedule of the Deep Space Network. Such deliberations and recommendations by the full SROP are complex and involve a plethora of compromises.

Next year, the SROP will develop a recommendation as to which of the Jovian satellite tours generated by the Navigation Team should be selected. One of the things the Team will consider will be how to maximize the number of satellite encounters and how to strike a balance with the conflicting observing regimes of different instruments. One conflict, for example, involves the Solid-State Imaging System, which needs to image a well-lit landscape with deep shadows for contrast, and the Near-Infrared Mapping Spectrometer, which requires a well-lit landscape with no shadows. The same tour must accommodate both instruments, with some obvious compromises in store. After the SROP negotiates such compromises, the Project Science Group has the final authority.

The next few years will be busy ones for the SROP. The plans for the Gaspra flyby are now at the final stage. Satellite tour selection will begin in January and continue through June 1992. The *Orbit Planning Guide*, the overall mission experiment design by the PIs and the first-order agreements for sequencing, is due in September 1992. (The *Orbit Planning Guide* for the 1986 mission was completed in 1985, and the Team may be able to reuse a significant portion of that *Guide* for this mission.) Activity-level plans for the remainder of the mission will continue through 1994 for whichever tour is selected.

The soft-spoken gentleman who will continue to lead this group of negotiators is Jim Dunne. Just as the products of his Team move from person to person, becoming more and more sophisticated with handling, so too has Jim's work in aerospace become more sophisticated as he has moved from project to project.

Jim received masters' degrees in biology and geology from Hofstra University and then a doctorate in mineralogy from Columbia.

In 1960, he began working at Philips Electronic Instruments, researching applications for an advanced x-ray instrument for mineralogy. "But," Jim notes, "I became more interested in instrument design than in applications. I became an instrument scientist rather than a mineralogist."

Moving into this new arena, Jim worked on the development of an x-ray diffractometer for the Surveyor Project, elucidating the mineralogical and petrological capabilities of this instrument. He moved with the instrument to JPL in 1964, to head up a program on the application of x-ray diffractometry to lunar studies.

As Surveyor finished, the Mariner 6 and 7 missions were looking for someone to take charge of their image processing. Enter Jim Dunne. Jim decided he had become "more interested in the spacecraft than in an individual instrument." Later, as Project Scientist for Mariner 10 (Venus Mercury), Jim received valuable experience that would help him in his later negotiations in the SROP. More negotiation experience followed as he oversaw Seasat's ocean experiments.

In addition, he participated in several project studies, including the proposed American Comet Halley intercept mission.

During this time, he led a working group of the International Consultative Committee on missions to Halley's Comet. His group initiated the Pathfinder experiment, which used imaging data from the Soviet Vega spacecraft to provide final course adjustments to the European Space Agency's Giotto spacecraft, both members of the Comet Halley armada. Later, he was also the Manager of JPL's contribution to the Soviet Phobos mission to Mars.

Jim was appointed Galileo SROP Team Chief in 1983, and just this year was also named the Science and Mission Design Office Manager.

Up to Date (Cont'd)

activities. Of course, additional sequences have been prepared and sent for the various HGA cooling turns.

Because the HGA warming maneuver did not result in any perceptible changes to the HGA, the Project directed that the Gaspra encounter be planned using the low-gain antenna and the onboard data storage capabilities of the Data Management System (DMS). All work on the EE-2/EE-3 sequences that presupposed the availability of a fully unfurled HGA was terminated. New sequences EE-2 prime and EE-3 prime are being developed to carry out the Gaspra encounter.

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The Galileo Messenger

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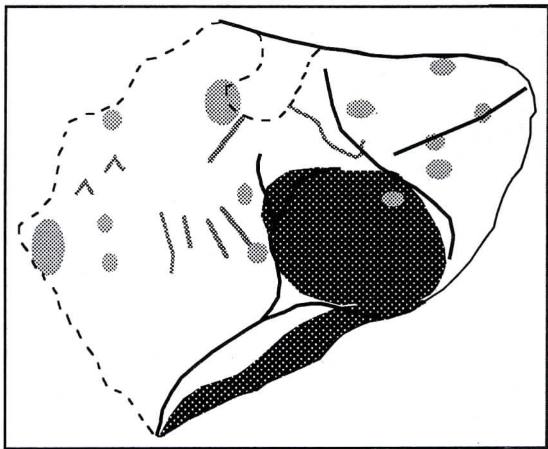
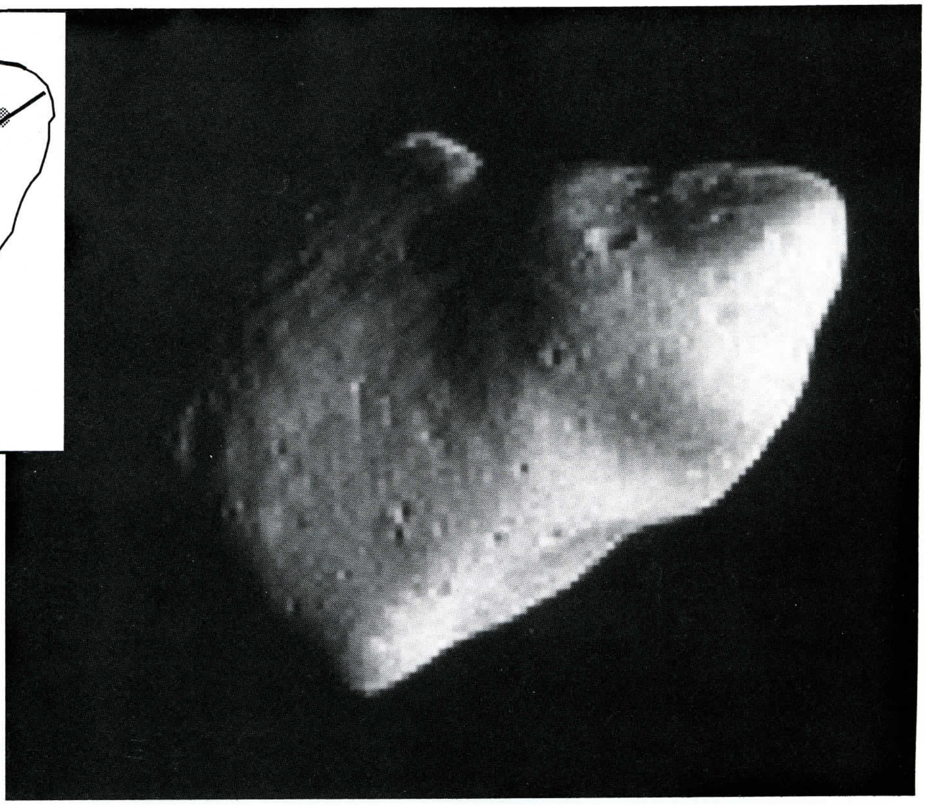




The first image of asteroid Gaspra was taken by the Galileo spacecraft on October 29, from a distance of 16,200 kilometers (10,100 miles). The Sun is shining from the right. The illuminated part of the asteroid is about 16 by 12 kilometers (10 by 7.5 miles). The surface shows many craters; two large facets about 8 kilometers (5 miles) across appear on the limb of the asteroid at the top and bottom right. The smallest craters in this view are about 300 meters (1000 feet) across. Gaspra's north pole is near the upper left corner of the lighted part of the asteroid. The inset illustration points out the major craters, ridges, and depressions on the asteroid. (P-39432)

From the Project Manager

Except for the High-Gain Antenna (HGA), Galileo continues to perform beautifully. The success of our low-gain-antenna (LGA) based encounter with Gaspra far exceeded all expectations. The Galileo Flight Team and spacecraft and the Deep Space Network and Mission Control and Computing Center (MCCC)

— see page 8

An Encounter With Gaspra

In setting out to have the first spacecraft encounter with an asteroid, the Galileo Project determined several goals. Foremost, the scientists wanted to characterize the asteroid (its size, shape, and cratering record), to learn about its composition, and to survey the surrounding environment. From the initial results received, the Gaspra encounter was a resounding success.

The Galileo spacecraft flew past the tiny asteroid on October 29 at 2:37 P.M. (PST), traveling at a relative velocity of 8 kilometers per second (17,895 miles per hour). At closest approach, Galileo was just 1.5 seconds and 5 kilometers (3 miles) from the aim point—a bull's-eye in planetary distances. Dr. Michael Belton, Solid-State Imaging Experiment Team Leader, said, "The key word out of this encounter is *precision*. It was like taking a picture of a large house in San Francisco from Los Angeles." In fact, the pointing was dead-on—Gaspra was in the central image of the nine-image mosaic taken about 30 minutes before closest approach.

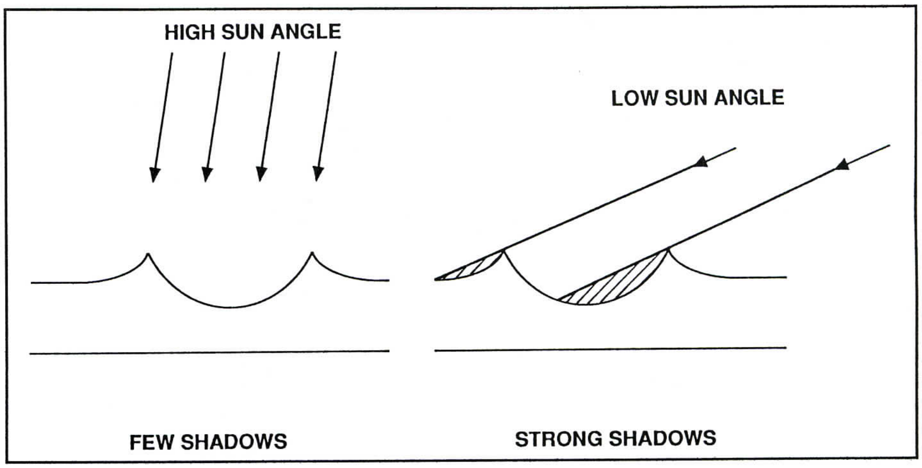
"The team has been extremely ambitious about going for all they

can with the Gaspra encounter. It's been a shot in the arm," emphasized Project Manager Bill O'Neil. In fact, because the spacecraft is currently constrained to low data rates, the Project had planned not to have any data available until either the High-Gain Antenna (HGA) is deployed or November 1992. Because of the excellent targeting by the Flight Team, four images have already been retrieved. These four images comprise one full-color image.

For the first Gaspra images to send back, the team members selected a frame that, based on their calculations, had well over a 95 percent chance of containing Gaspra's image. These images have a resolution of about 170 meters per picture element; the best image, with about a 50-meter resolution per picture element, remains on the tape recorder awaiting playback next year. "The camera is operating absolutely to specs; it's first rate. We were overjoyed when we saw the first 12 lines of the image and realized we got the asteroid right on target," noted Dr. Belton.

The first portion of these images came back on November 5. At Galileo's distance from the Earth, downlink data rates via the low-gain antenna (LGA) were limited to 40 bits per second. At this rate, approximately 72 hours are required to transmit a full, 800-line imaging frame. At this Gaspra–spacecraft range, the asteroid was contained in just an eighth of the entire frame; thus, only 100 lines had to be transmitted to receive the entire image. Once the HGA is open, the time to transmit one full, 800-line image will be just one minute.

Another adjustment due to the low data rate was that Galileo was targeted to pass closest to Gaspra on its shadowed, rather than sunlit, side. That trajectory offered the best chance to view craters and other surface features in crisp relief along the day–night terminator. Unfortunately, such a path precluded spectral and photometric observations over as large a range of lighting angles as would be achievable using a bright-side passage.



When the spacecraft captures an image at low sun angles, the long shadows help scientists see more details.

From ground-based observations, quite a bit of information was known about Gaspra before the encounter. Discovered in 1916 by astronomer Grigori Neujmin at Simeis Observatory in the Ukraine, Gaspra was named for a scientists' resort on the Crimean Peninsula. Gaspra, an S-type asteroid, is believed to be made up of metallic and rocky minerals, including iron, nickel, olivine, and pyroxene. This asteroid is just one of more than 5000 comprising the "main belt"—a large doughnut-shaped region midway between Mars and Jupiter. Gaspra is located about 331 million kilometers (206 million miles) from the Sun, near the inner edge of the main belt. Asteroids are also known as minor planets; many are much larger than Gaspra, ranging up to more than 800 kilometers (500 miles) in diameter.

Gaspra is believed to be a "collisional fragment of a larger parent body, a survivor of a series of catastrophic events," noted Joe Veverka, a member of the Imaging Team. In fact, Gaspra's current size may be only a tenth of its original size.

Investigating Gaspra will be important to scientists because asteroids may contain important clues to processes in the early solar system. Asteroids are believed to have formed during the earliest stages of the solar system and thus are primitive bodies that could shed clues about the evolution of the Sun and its planets. Asteroids could have been spawned when the other planets were formed in the early solar nebula or they could be the remnants of an incomplete planet formation between Mars and Jupiter.

Another significant reason for encountering Gaspra was to help calibrate ground-based observations. Since all previous observations of asteroids have been limited to ground-based viewing, Galileo's encounter provided a unique opportunity to verify our assumptions and analyses based on our limited information.

Project scientists have been able to ascertain many facts about Gaspra from the initial data received. Gaspra is 20 kilometers (12.4 miles) long and 12 kilometers (7.4 miles) wide, as well as 11 kilometers (6.8 miles) thick.

Because the asteroid is small, its gravitational force (0.0005 g) is two thousand times smaller than the Earth's gravity, yielding an escape speed of a scant 10 meters per second (22.3 miles per hour). Since the gravitational force is so low, when something impacts with Gaspra, most of the dust and material from the resulting collision fly off the asteroid. With these conditions, scientists expected to see sharply defined craters and ridges, since there

should have been little, if any, surface rubble (called regolith). What is surprising about Gaspra, then, is its subdued appearance. There may be a small layer of regolith on the surface. As yet, scientists cannot tell how deep this layer may be, but initial estimates are from a few centimeters to a few meters. Scientists did note, with relief, that the Dust Detector registered no dust impacts during the encounter, indicating a very clean environment around the asteroid.

The degree of cratering seen on the asteroid's surface can tell volumes about Gaspra's origin and evolution. Project Scientist Dr. Torrence Johnson noted that the images of the surface were "better than expected. We had hoped to see the asteroid's shape and maybe a couple of craters. While we know quite a bit about this object statistically from ground analysis and observations, there is still lots of controversy about details."

What is discernible about the surface are major depressions, indentations, ridges, and craters. Some of these craters are as wide as 1.5 kilometers—indicating, for example, an impact with a body 100 meters (330 feet) in size, traveling 5 kilometers per second (3.1 miles per second). Gaspra has probably existed in its present form for the last 200 to 500 million years. Another initial observation is that the albedo is relatively homogeneous, although there are noticeable variations in albedo and color at about the 10 percent level.

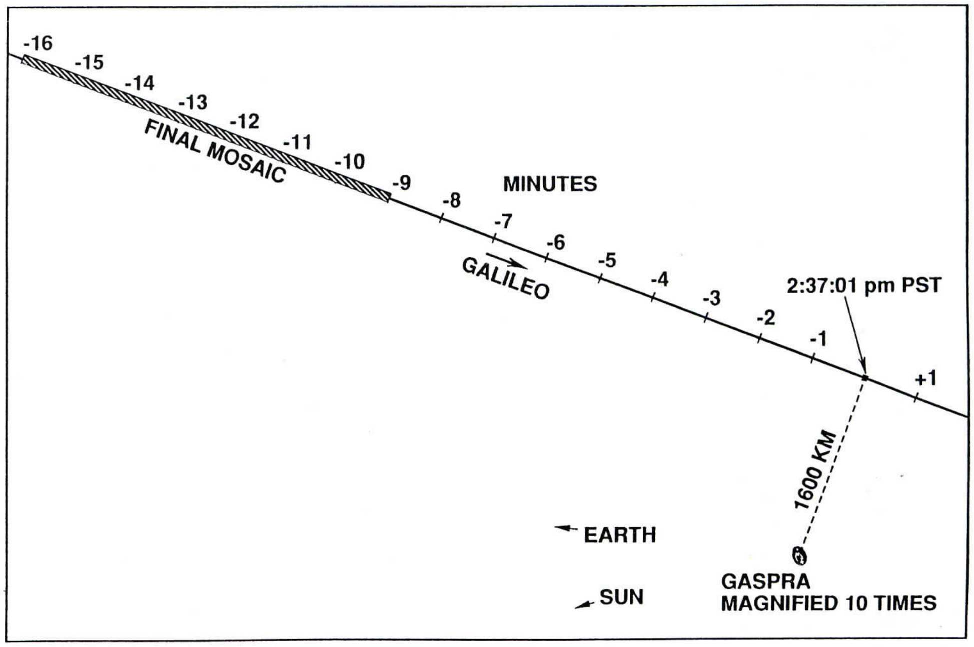
The question of what materials actually comprise Gaspra is one that cannot be answered until the rest of the data are received by Project scientists. The main tool in revealing Gaspra's composition involves spectral scans by the Near-Infrared Mapping Spectrometer (NIMS). Dr. Robert Carlson, the NIMS Principal Investigator, noted that the low-resolution data he has received so far suggest compositional differences between Gaspra's northern and southern hemispheres. The clearest evidence of what constitutes the asteroid's interior might be found if further NIMS data reveal fresh craters that expose subsurface material.

As for the future, the Project scientists are eagerly awaiting the rest of the data from the encounter, including an additional 15 images of Gaspra. Slated to be returned either when the HGA is deployed or in November 1992, the information stored on board Galileo will answer many of the questions we have about asteroids and early solar system materials. Undoubtedly, many questions will also be raised by the brief glimpse we will be getting of this one asteroid.

The information still on board Galileo includes the remaining NIMS data, which should reveal a plethora of facts about Gaspra's composition. In addition, one of the images yet to be transmitted has a resolution about 3.5 times better than the full-color image already received. With a resolution of about 50 meters per pixel, combined with lower Sun angles (which yield longer shadows) in these images, more details will become apparent. Referring to several features that are almost resolved in the images received so far, Dr. Veverka noted, "The images we've seen give us high confidence that the rest of the images will be excellent. We're at the limit of our resolution with these first images. We cannot tell if these are ridges or are grooves caused by an impact that didn't quite break up the asteroid." In the later image, these features should be resolved.

One of the potential plans the Project has to gain a better understanding of asteroids is to repeat Galileo's recent performance by flying past asteroid Ida in August 1993. The success of the team and the spacecraft at Gaspra will certainly be considered by the Project as it develops future plans. However, the final decision will be made in the summer of 1992 and will consider the spacecraft's status and propellant needs at Jupiter as well. The comparison of these two S-type asteroids would help scientists to further calibrate and verify ground-based observations of asteroids, as well as to analyze the range of characteristics that may exist in similar asteroids.

Joe Veverka summed up the Imaging Team's enthusiasm. "We are reading another page in the exciting history of this asteroid." A second chapter on asteroids, entitled Ida, may still be to come.



Galileo's trajectory past tiny Gaspra was swift.

From the Mission Director

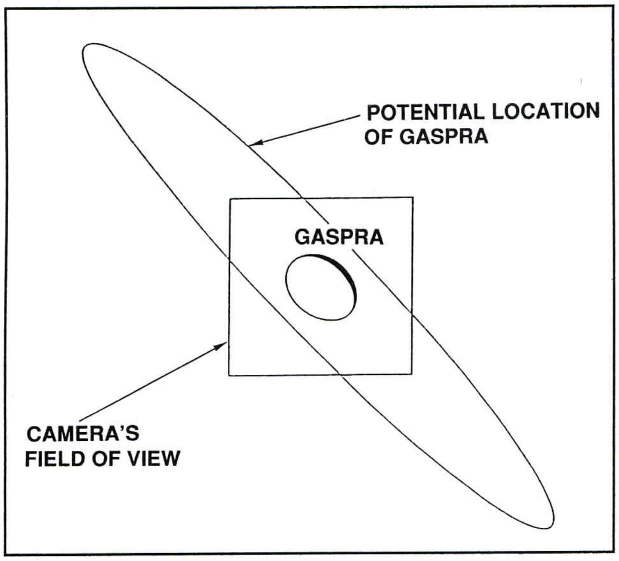
The Gaspra encounter posed significant operational complications to the Galileo Flight Team. Perhaps the most demanding aspect of the encounter was the requirement to keep the Gaspra HGA option open until the last opportunity and then to completely replan the Gaspra encounter using the LGA and three tracks of the DMS. In May 1991, the Project decided on the LGA-based encounter shortly after the first warming turn failed to result in an HGA rib release, only five months before our October 29 date with Gaspra. The normal encounter uplink design process from the specification of detailed science requirements to the transmission of the resulting sequences takes approximately 10 months; thus, the Flight Team had to complete its design job in less than half the normally allocated time.

In addition to the new and unique operations required for Gaspra, the Flight Team had to be ready to "tweak" all the scan platform observations planned to occur during the final four hours of the Gaspra encounter. In the worst case, the "starting gun" for developing the tweak commands would not be sounded until Optical Navigation Image 5 data were returned a scant 28 hours before the Gaspra encounter data were actually to be taken. In addition, there was the threat of a spurious CDS-bus-reset induced safing—if it had occurred within 76 hours of the closest approach, the entire encounter sequence would have been halted and all of our efforts to capture a first image of Gaspra would have been wasted. To protect the encounter outside this 76-hour period, the Flight Team developed a contingency plan that would have allowed for safing recovery and the uplink of the Gaspra close encounter sequence (EE-3 prime) as planned. By itself, the development of this contingency plan represented a very substantial effort.

The following items identify some new operational efforts required for the Gaspra encounter.

First, optical navigation-image data-taking plans had to be developed that involved periodic motion of the scan platform while the SSI shutter remained open so each image would effectively produce multiple observations of Gaspra within the field of background stars. The DMSMRO, originally designed to return the selected science data shortly after the Venus encounter, had to be adapted to operate at 40 bits per second. Tracking station coverage had to be renegotiated to match the TCM-12 cutoff window and to assure the availability of each of the four optical navigation images on a carefully thought-out schedule. New operational software had to be developed that would help manage the processing of optical navigation data as they moved from the spacecraft to the DSN and, in turn, to the MTS, MCCC Image Processing System (MIPS), and Optical Navigation Image Processing System (ONIPS).

A software Reed–Solomon decoder had to be developed to provide for required MIPS computer redundancy. This effort was undertaken to assure no delay in the processing of time-critical Optical Navigation Image 5 data. Finally, five MTS software patches were necessary to assure the processing of optical navigation data that would be interrupted by long-term gaps in the tracking coverage, as well as short-term gaps caused by periodic data system outages as data were collected on the ground and relayed to the telemetry processor at JPL. Since it took a minimum of 72 hours of 70-meter antenna tracking station coverage to recover a single optical navigation imaging frame, the data were packaged as efficiently as possible by the CDS. Correspondingly, interruptions in data flow, however brief, caused the MTS to temporarily lose lock and an attendant loss of two to four lines of possibly crucial optical navigation data. These MTS patches successfully dealt with the unavoidable data interruptions.



Because of the excellent work by the Flight Team, at just 10 minutes before closest approach, Galileo's camera was able to pinpoint Gaspra's location.

The performance of the Flight Team was exemplary. The results of the optical navigation campaign, including the very demanding capture of all required data by the DSN and its expeditious processing by each of the various facilities on the ground, were outstanding! The Gaspra position uncertainty associated with the tweakable observations was so much better than expected that the pointing tweak was avoided altogether. The DMS modeling was so good that the Flight Team was able to return a four-filter version of the remarkable, 76-line image of Gaspra in the time allotted for a single version of this image.

My very highest hopes for our Gaspra encounter paled in comparison to the demonstrated achievements of the Flight Team. I am proud to be a member of this extraordinary Team.

—Neal Ausman
December 1991

Up To Date

This last quarter has been a busy one for Galileo. In addition to normal activities, like trajectory correction maneuvers and uplink command generation, the unique challenge of preparing for and executing the Gaspra encounter was met. A long-term effort was initiated to convert Galileo support from the Mission Control and Computing Center (MCCC) to the Space Flight Operations Center (SFOC). Additionally, design and transmission for the High-Gain Antenna (HGA) third cooling turn sequence were completed. Finally, investigation of spacecraft anomalies, such as the Command Data Subsystem (CDS) unexpected lock change counts, is continuing.

SFOC Activities

After initial SFOC training of Galileo personnel and installation of Phase I workstations in the Galileo Mission Support Area (MSA) in Buildings 230 and 264, the Flight Projects Support Office (FPSO) and SFOC management informed the Project that Galileo work on SFOC Versions 17 and 18 was being suspended. The Galileo conversion work will resume after Version 18 is complete. Preliminary impact assessments by FPSO and SFOC indicate an 18-month slip, giving a new SFOC operations and MCCC decommitment date of June or July 1994.

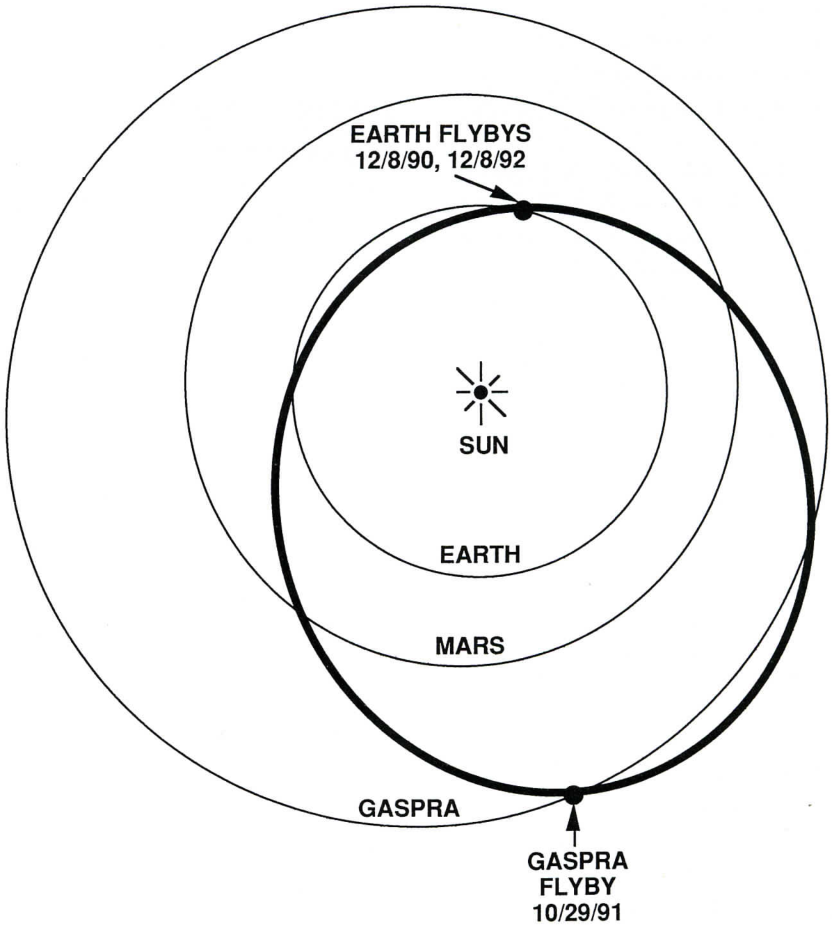
DSN Activities

Ground Data System (GDS) tests of the Deep Space Network (DSN) Telemetry Processing Assemblies (TPA) were conducted to characterize the performance of the Type A and Type B telemetry strings in accurately determining spacecraft clock drift and correlation with UTC time. A special telecommunication spacecraft-to-DSN end-to-end test was performed on August 23 to characterize the telemetry link performance at 10 and 40 bits per second using the spacecraft's low-frequency subcarrier (22.5 kilohertz). Preliminary results indicate link performance improvements on the order of 0.7 to 1.5 decibels, depending on the spacecraft data rate and TPA being used.

Assessing Anomalies

About nine months ago, a special team was formed to thoroughly investigate the unexpected lock change count events that have been occurring on the spacecraft. A lock change count event normally occurs both prior to and after a planned command uplink message from the Command Detector Unit (CDU) to the CDS. The CDS counts the CDU in-lock and out-of-lock events and telemeters their occurrences. After intensive review of the flight data and all pertinent DSN station configuration and procedural information, the cause for most of these spurious lock changes is still unknown. Recent investigation efforts have focused on the spacecraft receiver and the command hardware interface between the CDU and the CDS.

A Project status briefing on November 5 focused on the 18 unexpected CDS lock change events observed since September 1990; unexpected lock change counts have been observed at Deep Space Stations 14, 43, 61, and 63. In all instances, the spacecraft never processed or issued an unwanted command; the spacecraft continues to respond properly to planned commands. Two common conditions identified among the events were: the spacecraft was in two-way mode and the uplink-received signal strength was low (but still several decibels above threshold). Furthermore, investigation confirmed that two of the events were



Galileo is now less than a year away from its second and final encounter with the Earth. At that time, scientists plan to glean more information about our own planet, as well as relaying the rest of the Gaspra data stored on the spacecraft.

ground-induced due to procedural errors. The cause for the remaining events is still unknown. A spacecraft hardware failure or an electrical-noise-sensitive electronics component in the CDU have been identified as possible causes, but neither is thought to be a credible fault scenario. Another possible cause could be normal operation; i.e., when the spacecraft receives a low-strength signal and the signal frequency sweep rate is low, the spacecraft hardware may generate spurious lock change counts.

A laboratory test will be performed using the appropriate radio frequency receiver and CDU hardware to characterize the command hardware performance at various signal strength levels and sweep rates in addition to other pertinent operational conditions. Similar unexpected command lock change counts were observed on the Voyager and Viking spacecraft, which use similar command element hardware. No unexpected command lock change counts were identified during Galileo's development and test period.

Since being commanded to dual-spin operation on September 6, Galileo has not experienced a CDS bus reset anomaly. The last bus reset anomaly occurred on July 19 when the CDS "A" string experienced a spurious transient event thought to be a result of slip-ring brush debris. The other two system anomalies—the AC/DC bus imbalance and the despun critical controller 2A POR telemetry indication—did continue to exhibit some activity.

The AC/DC bus imbalance measurements have remained fairly stable over the last several months; no significant variations were observed in these measurements during cruise, maneuver, and Gaspra encounter activities.

Two more anomalous despun critical controller 2A POR telemetry indications were observed on November 22 and 30. The spacecraft telemetry signature of these occurrences was identical to the previous 12 occurrences. As on all other occasions, these were spurious transient events and the telemetry status was reset by ground controllers.

Galileo Mission Summary*

Distance from the Earth	462,677,903 kilometers (287,494,720 miles)
Distance from the Sun	337,869,613 kilometers (209,942,444 miles)
Distance from Jupiter	1,082,751,855 kilometers (672,790,811 miles)
Round-Trip Light Time	51 minutes, 16 seconds
Velocity Relative to the Sun	15.15 kilometers per second (33,890 miles per hour)
Spacecraft–Sun Angle	5.5° off Sun
Spacecraft Spin Rate	3.15 revolutions per minute
Spin Configuration	Cruise mode, dual spin
Downlink Telemetry Rate	10 bits per second (Low-Gain Antenna 1)
Powered Science Instruments	Dust Detector Subsystem, Energetic Particles Detector, Extreme Ultraviolet Spectrometer, Heavy Ion Counter, Magnetometer, Plasma Wave Subsystem, Solid-State Imaging Subsystem, and Ultraviolet Spectrometer
General Thermal Control	All temperatures within acceptable ranges
RTG Power Output	532 watts
Real-Time Commands Sent	6052 commands

*All information is current as of December 5, 1991.

Activating the Thrusters

Maintenance "flushing" of the Retropropulsion Module (RPM) 10-newton thrusters continues at periodic intervals. The S, L, and Z thrusters were "flushed"; the P thrusters are generally not "flushed" during these exercises because they are used periodically for attitude maintenance and other events. Spacecraft response throughout all the "flushing" exercises was normal; thruster temperature profiles were similar to those observed in all other previous "flushing" operations.

Trajectory Correction Maneuvers (TCMs) 11 and 12 were performed on October 9 and 24, respectively. These were the first maneuvers to be performed at the 10 bits-per-second telemetry rate and at an Earth-pointed attitude (about 25° off the Sun). All RPM pressures and temperatures and attitude control indicators were near predicted levels.

Five SITURNs were performed during this period, including a 3° SITURN on August 25 to reduce the Sun-lagging attitude from about 6° to 3° in preparation for the Solid-State Imaging (SSI) cover deployment activity on September 5. The cover jettison pyrotechnic event was verified from pyrotechnic engineering telemetry. Within two hours after the pyrotechnic event, the SSI front optics temperature dropped 2 DN, thus providing some SSI engineering data to confirm that the cover was removed.

Analyzing the HGA

Continued analysis, modeling, and testing of the HGA support the earlier finding that the HGA's most likely condition is that three ribs are stuck in the stow position, no damage has occurred to the motor drive mechanism, and no structural failure has occurred in the drive train. Therefore, if the ribs can be released, full capability to open the HGA is available.

Recent analyses of the cooling turn activities suggest that the alignment pins may be slowly "walking" out of the receptacles. The analyses further suggest that

alternating maximum warming and maximum cooling turns provides the best prospect of "freeing" the ribs. Consequently, in addition to the December 1991 cooling turn, three alternating warming–cooling turn activities have been planned between January and the end of April 1992.

Flying by Gaspra

The Galileo Gaspra closest approach (1600 kilometers, 1000 miles) occurred on October 29 at 22:37:01 UTC. This was the first spacecraft encounter with an asteroid. As planned, all the Galileo science instruments, except the Heavy Ion Counter, collected data. A total of 150 images were taken, and 126 of those were taken within an hour of closest approach. All data were stored on the tape recorder (DMS) for subsequent playback.

Although the telemetry sample rate was low (10 bits per second), selected engineering measurements enabled the Flight Team to determine in real time that the spacecraft was properly executing the encounter sequence. The selected measurements included tape recorder position, scan platform position, scan platform mis-slew count, power consumption, and the number of commands sent to the SSI.

While the Gaspra encounter sequence was being executed, several engineering telemetry channels went into alarm status, thus precluding *complete* real-time confirmation of sequence operation. A quick review of the CDS software revealed that when telemetry is operating at 10 bits per second, commanded telemetry mode changes can disrupt the engineering measurement commutation process and interrupt sampling of all the engineering measurements, causing alarms. Because of the planned numerous telemetry mode changes in the Gaspra encounter sequence, engineering telemetry was often disrupted. However, even with the disruption, adequate real-time telemetry was available to conclude that the spacecraft was, indeed, executing the sequence.

Four Gaspra images have been retrieved. These images were returned from the tape recorder via the spacecraft's low-gain antenna at 40 bits per second using the same DMS memory readout (DMSMRO) technique used to return early Venus images in February 1990 and the Gaspra optical navigation images taken in September and October 1991.

Delivering Software

The MCCC Telemetry Subsystem (MTS) C4.1 waiver delivery, completed on September 4, provided a new algorithm for processing spacecraft tape recorder data readout via the CDS memory. The new algorithm greatly improved performance and data recovery during readouts of optical navigation pictures in support of Gaspra. The Optical Navigation C4.1 waiver delivery, completed September 4, provided enhanced single-frame mosaic capabilities to support processing of the optical navigation data for Gaspra.

The C5.0 software development activities, which included the delivery of 23 programs, were completed November 4. The C5.0 deliveries provide updates to capabilities necessary to support Earth 2 uplink design activities, final tour design activities, and Gaspra non-real-time downlink support enhancements.

The Integrated Release Description Documents (IRDDs) covering the C4.1 and C5.0 Mission Build software deliveries were published August 15 and November 19, respectively.

Generating Uplink Commands

The EE-2 (Earth–Earth) prime sequence, controlling spacecraft activities from September 3 to October 28, included four optical

— see page 8

Mission Readiness Tests

The Project recently successfully completed a series of combined Deep Space Network (DSN) Mission Readiness Tests (MRTs) and Project Ground Data System (GDS) tests. These end-to-end tests demonstrated the readiness of the DSN and GDS to support the Gaspra encounter. The Gaspra MRTs also ensured adequate backup equipment for the low-gain antenna (LGA) encounter. With the LGA, Galileo is limited to using the 70-meter antennas, of which there is only one at each DSN site. This could then become a single point of failure. The Project had arranged backup systems for everything; for example, diesel generators were checked and prepared at each site in case of a power failure. During the Gaspra encounter, because unexpected things occurred, like a failure of the prime maser at DSS 14 in California, many of these backups were used.

Robert C. O'Connor, DSN Operations Project Engineer, prepared and coordinated these tests, assisted by Michelle Andrews. O'Connor noted, "The MRT is a DSN validation that all the hardware, software, procedures, and personnel are in fact ready to meet the Project's requirements for completing the plans of the mission."

MRTs use all or more DSN resources than does a live track. The tests could be simplified by using the spacecraft as a test vehicle—running a live test—but that can be risky if the test had any flaws. Instead, the Project normally creates a complete simulated test, which is far better, but far more difficult to prepare.

Due to its complex mission, Galileo has had more MRTs than most projects that the DSN

supports. Before launch, about 50 MRTs were performed to meet all the requirements of the launch and cruise portions of the mission, and to prepare for as many contingencies as possible. At that time, the Project was mainly verifying there were redundant systems in case of any failure in the ground system (like inclement weather at one of the DSN sites). With the low transmission rate of the LGA, there simply is no capacity for error. The team also developed a specific series of tests for each major encounter (Venus, Earth, Gaspra, and Earth again). These test series were each unique challenges. The team had to develop and conduct the tests, and then to validate that all the existing parameters and upgrades were functioning smoothly.

When preparing for a test, O'Connor and Andrews always need to look at whether anything has changed in the equipment, software, or procedures. A small change in any area could affect the end-to-end data recovery. In addition, because personnel change at the various DSN sites, a periodic test is necessary to confirm that all the people have been adequately trained.

The MRTs test the ability of the DSN to support the mission in real time and of JPL to provide all the support documents, like the sequence of events, in real time. "The measure of a good test is not how successful it is, but how comprehensive it is," pointed out O'Connor. "We want to avoid surprises. We have to use the same tools (documents, software, and people) during the test that will be used during the actual event."

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From the Project Manager (Continued)

supporting organizations once again delivered a stunning performance for all the world to witness. What a joy it was to capitalize on the extraordinary navigation accuracy and inventiveness of the Flight Team by returning the data to Earth, processing it, and publishing the first-ever resolved image of an asteroid a year ahead of schedule—and in color!

As yet, we have had no joy in our HGA rib-release campaign; however, there is good reason to remain hopeful. A very sophisticated, detailed computer model of all the pertinent forces involved in the HGA was completed last fall. The model shows that for reasonably expected misalignments and friction, the locating pins (as shown in *The Galileo Messenger*, issue 28) do, indeed, "walk" out of their receptacles as the central tower is cycled up and down by alternate warming and cooling. Accordingly, we are now embarked on a very ambitious campaign of thermal cycling the HGA with alternating warming and cooling turns. Four cycles have been completed and eight more are planned between March 1992 and March 1993. The displacements of the ribs during the walking are much too small to detect in any spacecraft telemetry measurements. However, once the pin-pair of a given rib clears its receptacles, the rib will spring out, and this will be clearly indicated by data from the Sun gate sensor. The first of the three stuck ribs could release on any of the next turns. The model indicates one or more additional thermal cycles will be required between each of the subsequent rib releases. Every turn has the exciting potential of a rib release—stay tuned!

Detailed planning for the Earth 2 encounter is now in full swing. Recall that we must keep Galileo near Sun-pointed when the spacecraft is close to 1 AU from the Sun, so even if the HGA is open by Earth 2 in December 1992, it cannot be used for the encounter—the Earth encounters are necessarily LGA only. Spectacular, unique observations of the Moon and Earth will be made. These include our long-promised images of the Moon's north polar region as Galileo flies over the Moon 12 hours before Earth encounter and of the Moon–Earth conjunction as seen by Galileo eight days after encounter.

—Bill O'Neil

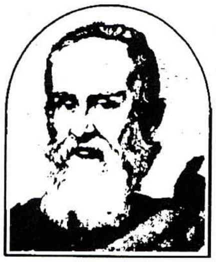
Up To Date (Continued)

navigation observations, three SITURNs, three RPM flushing activities, sixteen SSI memory readouts, and windows for TCM 11 and TCM 12. This marked the first time that spacecraft events were being controlled by a stored sequence since the safing entry in March 1991.

The EE-3 prime Gaspra encounter sequence, sent to the spacecraft on October 27, contained all the commands for the spacecraft to perform the Gaspra encounter activities. The EE-4A sequence controlled the spacecraft's activities from November 4 to December 4, 1991. The EE-4B sequence, presently in design, will run from December 20, 1991, to February 17, 1992.

The time window between December 4 and 20, 1991, is set aside for the third HGA cooling turn activities. The HGA third cooling turn sequence was sent to the spacecraft on December 4. The pre-cool portion of the sequence went active on December 6, and the cooling turn is scheduled to begin on December 13.

— Matt Landano
December 1991



The Galileo Messenger

Issue 30 September 1992

From the Project Manager

In just a few months, on December 8, 1992, Galileo will complete the VEEGA (Venus–Earth–Earth gravity assist) phase of its trajectory to Jupiter. EGA2, on December 8, will boost Galileo into its three-year, direct, Earth-to-Jupiter heliocentric transfer orbit. EGA2 is a very significant milestone. And, once again, we are looking forward to some spectacular observations of the Moon and Earth.

We have not yet succeeded in freeing the stuck ribs of the High-Gain Antenna (HGA). Fortunately, the most aggressive actions by far are still ahead of us. The thermal cycling of the HGA by warming and cooling turns to "stroke" the HGA central tower to try to walk the stuck locating pins out of their receptacles was abandoned in July after the seventh cycle. Performing seven cycles without even one rib releasing demonstrated that this technique cannot free the ribs—either the parameters are too adverse or the pin-walking model does not adequately represent what is restraining the ribs.

It is well to remember that, due to thermal contraction, the HGA was not at assembly dimensions at the April 1991 deploy attempt or

— *see page 8*

Up To Date

HGA Actions

Between January and April 1992, the fourth, fifth, and sixth warming and cooling turn activities were performed in an attempt to walk the High-Gain Antenna (HGA) alignment pins out of their receptacles to free the stuck antenna ribs. Another warming–cooling turn activity was completed on July 10. During the warming–cooling turn activities, the temperatures of various Galileo components were monitored. Heaters were turned on and off, as necessary, to keep the hardware within safe temperature limits and to maintain an adequate system power margin. Sun gate data, collected after each cooling or warming turn, indicated that an antenna rib still obscures

— *see page 2*

This image of Gaspra is a mosaic of two images taken by Galileo on October 29, 1991. Because the High-Gain Antenna has not yet been deployed, this high-resolution image was obtained via one of the low-gain antennas onboard Galileo. In the event the High-Gain Antenna is not deployed before the spacecraft reaches Jupiter, scientists expect to achieve 70% of the original mission, including 100% of the Probe's mission using the low-gain antennas. (P40449)

the sun gate signal, thereby confirming there was no rib release. Also, Attitude and Articulation Control Subsystem gyro-based wobble data showed no change in the wobble angle as a result of the warming and cooling turns, corroborating the sun gate obscuration data. Subsequent to the twelfth HGA anomaly review on May 7, the Project decided to cancel the planned future turn cycles, since it was concluded these remaining cycles would likely provide very little benefit to walking out the stuck pins.

On April 29, an HGA diagnostic motor turn-on sequence activity was performed for approximately two seconds to collect data regarding the HGA's present configuration. Analysis using the power system shunt current telemetry data collected at the highest possible sample rate indicated that the drive motors stalled approximately 100 milliseconds after turn on, indicating that the HGA drive system is still stalled. The wobble data collected after the turn-on verified that no ribs had been released from the motor action. Additional diagnostic motor turn-on activities are planned for late July and mid-September. Currently, HGA action plans are being developed that will take full advantage of the near-Earth solar environment for tower expansion and motor hammer actions.

An HGA technical workshop was held at JPL in June. The workshop was convened to provide an independent review and assessment of all the HGA anomaly-related efforts performed to date. Members included experts from the aerospace industry, other NASA centers, universities, the European Space Agency, and Department of Defense facilities. No new ideas were offered and no flaws were identified in the JPL problem assessment or action plan.

Galileo Mission Summary*

Distance from the Earth	268,514,000 kilometers (164,417,000 miles)
Distance from the Sun	292,085,000 kilometers (178,850,000 miles)
Distance from Jupiter	1,112,000,000 kilometers (680,917,000 miles)
Round-Trip Light Time	29 minutes, 36 seconds
Velocity Relative to the Sun	19.3 kilometers per second (42,600 miles per hour)
Spacecraft–Sun Angle	12° off Sun
Spacecraft Spin Rate	3.15 revolutions per minute
Spin Configuration	Cruise mode, dual spin
Downlink Telemetry Rate	40 bits per second, coded (Low-Gain Antenna 1)
Powered Science Instruments	Dust Detector Subsystem, Energetic Particles Detector, Extreme Ultraviolet Spectrometer, Heavy Ion Counter, Magnetometer, and Ultraviolet Spectrometer
General Thermal Control	All temperatures within acceptable ranges
RTG Power Output	525 watts
Real-Time Commands Sent	7961 commands

*All information is as of June 25, 1992.

Assessing Anomalies

During the pre-cool phase for the sixth cooling turn when the S-band traveling-wave tube amplifier was commanded to the low-power mode, the Radiometric Calibration Target (RCT) Near-Infrared Mapping Spectrometer nickel transducer telemetry indication went into alarm to a saturation reading of 255 data numbers (DN). However, after return from the cooling turn attitude, the nickel transducer telemetry initially read 201 DN, but then subsequently saturated at 255 DN and has remained there since mid-April. A 255 DN reading may be indicative of an open interface between the transducer on the RCT and the Command and Data Subsystem (CDS).

For the first two months of 1992, the AC/DC bus imbalance measurements remained fairly stable. For instance, at the end of the DSS 43 track on March 7, the AC bus imbalance was reading 223 DN (44.3 volts), where it has generally remained over the last two years. However, at the beginning of the DSS 43 track on March 8, the AC bus imbalance was found to be reading 13 DN (3.1 volts), a change of 210 DN. This was the first large fluctuation observed on the AC imbalance measurement since it began in December 1989. Other AC fluctuations were observed again in May and June, at one point dropping as low as 5 DN (0 volts), and then increasing up to about 3 volts. Such large imbalance fluctuations have been observed before, but only for the DC measurement. All these fluctuations are likely caused by conductive brush wear debris in the Spin Bearing Assembly, causing interface "shorts." These changes are consistent with the model developed by the AC/DC anomaly investigative team. As a consequence of the large AC measurement change, work was performed to analytically model the AC sensor/circuitry and to characterize the sensor hardware over a wide range of shunt leakage resistances. Additionally, a special test was performed on the spacecraft using the Energetic Particles Detector (EPD) to independently verify the 3.1 volt AC

imbalance reading. Because of EPD measurement resolution limits, the test was inconclusive in totally substantiating the imbalance reading, but the test did verify that adequate bias was still present on the EPD.

A total of 17 unexpected CDU lock change counts have been observed between September 1990 and December 1991. Three of these are known to be caused by ground procedural/operational errors. The remaining 14 are still under investigation, but are believed due to a single cause. Recent laboratory tests have demonstrated that under conditions of low frequency sweep rates and low uplink transmitter power levels, the spacecraft hardware can normally produce spurious command lock changes; further work is in progress. In no instance did the spacecraft receive a spurious command as a result of these lock-change anomalies.

While Galileo was being reconfigured after the fourth warming turn in January 1992, anomalous command and telemetry signatures were observed. The spacecraft downlink was configured in two way, the telemetry rate was 10 bits per second, the solar range was 2.27 AU, the Earth range was about 3.25 AU, and the spacecraft was about 6.3 degrees from the Sun and moving toward solar conjunction. On January 12, while over DSS 14, the CDS telemetry indicated that uplink bit errors were being detected, and a short time later the ground receiver automatic gain control and signal-to-noise ratio telemetry indicators showed a gradual 6-decibel performance drop, thereby precluding the processing of spacecraft telemetry data. Later that same day, while over DSS 43, similar degraded telemetry performance was observed, but for a short period the telecommunications link improved enough to verify that the spacecraft health was normal. Throughout this period, there was no evidence that the CDS processed or executed a command. An intensive, thorough investigation into the anomaly revealed that a design change made to Galileo's Voyager-inherited radio receiver made the receiver more sensitive to solar-induced noise effects. Later, when beyond the effects of solar conjunction, flight tests were performed that demonstrated all spacecraft command-related hardware is functioning properly.

Gaspra Science Return

Last November, four images of asteroid Gaspra were retrieved from the Galileo spacecraft. Data were returned on eight consecutive tracking passes at Australia in mid-November using a modified 40-bits-per-second Data Memory Subsystem (tape recorder) memory read out (DMS MRO) technique originally used at 1200 bits per second after the Venus encounter. The performance of the DSN, the Flight Team, and the Ground Data System were outstanding throughout the data retrieval process. In May and June, the spacecraft transmitted asteroid data to each of the three 70-meter antennas at Goldstone, Madrid, and Canberra, culminating in retrieval of the highest resolution Gaspra image on June 5, also using the DMS MRO technique. The remainder of the Gaspra science data on three tape recorder tracks is scheduled to be returned late this November, when Galileo is close to Earth and higher telemetry data rates are possible.

Reaching Aphelion

On January 12, Galileo went through aphelion (the trajectory point at which the spacecraft was farthest from the Sun) at a solar distance of 2.27 AU. Galileo entered the solar conjunction period on January 13 and exited on January 30; the minimum solar conjunction angle of 2.27 degrees occurred on January 22. During the solar conjunction period, telemetry quality was poor, as predicted, and therefore, it was difficult in real time to comprehensively assess the spacecraft thermal status. However, as the Sun–spacecraft angle increased, and the telemetry link improved, it was inferred from trend data that no abrupt thermal changes occurred.

Attitude Corrections

Six SITURN's were performed during the first half of this year. A SITURN, on April 27, oriented the spacecraft to a 16-degree off-Earth pointed attitude (Earth-lagging) to improve telecommunications performance. Using real-time commands, the telemetry rate was increased from 10 to 40 bits per second coded telemetry in support of the HGA diagnostic motor turn-on activities in late April.

Periodic maintenance, flushing, of the Retropropulsion Module (RPM) 10-Newton thrusters continues. On March 10 and May 12, ten of the 12 thrusters were flushed; the P-thrusters were not flushed because they were used to perform SITURN activities. Spacecraft response throughout all the flushing exercises was normal.

Navigation

During May and June, three navigation cycles were performed. These navigation cycles provided near-continuous acquisition of two-way Doppler and ranging data. These data will improve orbit determination in preparation

for the trajectory change maneuver TCM-14 scheduled for August 4 through 7. The TCM is expected to impart a delta velocity of about 21 meters/second.

GSOC Activities

The Operations Plan for the German Space Operations Center (GSOC) Operations Team was completed by GSOC and published in the Galileo Space Flight Operations Plan. The Plan documents the organization, personnel roles, and operating mechanisms to be used by GSOC to provide Galileo cruise science support after the HGA is deployed.

Ground Computing Activities

In early April, the Multimission Operations Systems Office (MOSO) IBM 3090/150 computer and the Management and Administrative Support Systems (MASS) IBM 3090/200 computer were merged into one mainframe computing environment configuration. The merge was accomplished without error and did not impact Galileo Data Management Team operations or flight software development activities. As a precautionary measure, the MOSO IBM 3090/150 computer temporarily remains at the Information Processing Center as a backup. A demonstration of the MOSO Galileo Multimission ground data system (MGDS) Command Subsystem Version 17.1 was given to the project on June 3.

On April 27, the Unisys Steering Committee reviewed year-to-date and future costs, as well as cost savings options. The committee decided that with the current version (version 39) of the Unisys operating system, the JPL security requirements cannot be satisfied. Therefore, implementing and testing of the Unisys operating system version 41 are proceeding; all project testing activities are scheduled for completion on August 17. A target date of September 1, 1992, was selected for projects to complete certification of their application software in this new operating system environment. The Galileo Project is now planning for this upgrade and formulating a plan and schedule, based on the availability of personnel and resources, to accommodate this upgrade.

Software Activities

On January 8, the Project Change Board approved two Project Change Directives and five Software Change Requests authorizing the Mission Sequence System to implement the remote-sensing looper capability. A remote-sensing looper consists of a remote-sensing science activity sequence that is loaded on Galileo as part of a stored sequence, but whose execution is repeated (looped) one or more times following completion of the activity's first instance. This new looper capability is needed to support remote-sensing science activities at Jupiter. This new capability will be delivered at the C5.1 and D1.0 Project Mission Builds.

The C5.1 and C5.2 software development deliveries, encompassing a total of 22 program sets, were completed on March 26 and June 18, respectively. These deliveries provided updates to capabilities needed for Earth 2 sequence planning and sequence generation activities, as well as downlink support enhancements.

—Matt Landano

Probe Checkout at Earth 2

The upcoming Earth 2 activities include a Probe Mission Sequence Test (MST) and an abbreviated Probe Checkout. As defined by the Probe Engineering Team, the normal Probe checkout consists of a systems functional test (SFT) and an MST. The SFT provides a complete functional test at the subsystem level, while the MST thoroughly tests the actual Probe mission sequence, including the operation of the data and command processor and the Neutral Mass Spectrometer (NMS) valves. To date, only the SFT has been performed in flight, once eight days after launch and again at Earth 1. Dr. Hasso Nieman, Principal Investigator for the NMS, requested that the MST be performed periodically to cycle the NMS' valves to ensure its proper operation as the Probe descends through the Jovian atmosphere on December 7, 1995.

A full checkout of the Probe is planned prior to its release in July 1995. However, if the High-Gain Antenna (HGA) is not deployed by that time, in order to reduce the data playback time an abbreviated procedure will check only what is mandatory and could be corrected prior to release. This abbreviated checkout will also be verified at Earth 2. If the HGA is not successfully deployed, the activities at Earth 2 will provide a final thorough test of the Probe, including its scientific instruments. Consequently, the Probe Engineering Team and the Probe Science Team are eagerly anticipating the challenge of the Probe activities at Earth 2.

—Pat Melia

Keeping the Ground Systems Office Running on Track

A large and complex project like Galileo requires a correspondingly large number of complex computer programs and ground system capabilities to support spacecraft operations. The monumental and crucial task of coordinating the developing, implementing, and testing of these ground system capabilities is overseen by the Ground Systems Office (GSO) managed by John McKinney. The GSO coordinates and system engineers new Project and multi-mission data system capabilities that are added to Galileo's support baseline. The GSO also verifies that these additions are compatible with the Project's needs. The GSO is a staff-level office that reports to the Mission Director.

The specific tasks of the GSO include Mission Operations System (MOS) engineering (including leading the MOS Design Team, when active), Ground Data System (GDS) engineering, GDS integration and test, Project software management and systems engineering, configuration management, MOS training, Project computer security management, Central Software Library management, and Project documentation support.

Much of the GSO's work involves managing and system engineering of software funded by the Project. Wayne Sible, the Ground Software Manager, and Susan Braun Alfaro, the Ground Software System Engineer (GSSE)

The Ground Systems Office coordinates the variety of ground support systems necessary to keep Galileo performing well. The GSO staff members are, from left to right, seated, Frederick Melikian, Katrina Walker, Dick Halverstadt, Betty Sword, and Georgia Stuffelbeam, and standing, Betsy Wilson, Pat Laubert, Larry Bryant, Ed Garcia, Wayne Sible, and John McKinney. Susan Braun Alfaro is not pictured.

perform these functions. Wayne and Susan are not specifically tasked with developing the software (that is the responsibility of the Galileo Flight Team). Rather, they coordinate the software development, interfaces, and deliveries—no small feat, since the Project software includes nearly 3.4 million lines of code and 193 software interfaces. The software development teams will be rather busy this summer as they must deliver 2.7 million lines of code by September 1992.

As GSSE, Susan conducts the required system integration testing (SIT) to ensure correct data flow and performance for the Project software. Wayne and Susan also conduct the System Engineers' Monthly Report (SEMR) meeting to review the status and plans for the software development. The SEMR is attended by the office managers and team chiefs and focuses on the development process, accomplishments, problems, high priority failures, action items, plans, and schedules. Susan and Wayne produce a summary report for the Mission Director after each SEMR.

In addition to substituting occasionally for John as acting Office Manager, Wayne was involved in developing the plan for bringing the Project software to the Level 41 operating system on the Unisys computer. He recently completed the task of coordinating the Project testing of the level 41 Unisys upgrade and the testing required to transition the Galileo application software to the new IBM 3090 computer. This activity represented the merging of Flight Projects Office and Administrative Computing into a more cost-effective computing environment. In addition to his Galileo duties, Wayne also supervises the Software System Management Group in Section 317.

As Galileo Multimission GDS (MGDS) Telemetry Conversion Engineer, Betsy Wilson represents the Project in its conversion from the Mission Control and Computing Center (MCCC) to the MGDS (formally the Space Flight Operations Center) telemetry support capabilities. MGDS telemetry, while providing many of the same capabilities as the current system, will feature an entirely new user interface. Betsy will work with the implementers and users to ensure that requirements are well-defined and understood and that the MGDS will provide all necessary support of Galileo operations. Betsy coordinates a Telemetry Conversion Working Group, whose goal is to keep the lines of communication open between the users and implementers.

Richard Halverstadt is the Galileo Central Software Library Manager and Computer Security Administrator. In that capacity, he audits the software deliveries, ensures they are correct and complete, and coordinates production of the Mission Builds that contain the operational software. Dick is supported in producing the Mission Builds by the Project Software Configuration Control Group, funded by the Mission Operations System Office (MOSO), consisting of Gina Nelson, Liz Castro, Marlyn Garapetian, and led by Mark Dawson. As Computer Security Administrator, Dick ensures that the Galileo support computers meet JPL's stringent security requirements, which exist to protect against hackers and computer viruses. He has developed a plan for computer security that will be implemented for Earth encounter later this year.

Once the individual data system capabilities have been developed and tested, it will be necessary to integrate the individual programs and test the overall support capabilities to ensure that Galileo support requirements can be met. GDS Integration Engineer Betty Sword conducts the critical GDS tests to verify the end-to-end data flow from the Deep Space Network (DSN) through the MGDS to the Project, or in the case of cruise science operations, from the German Space Operations Center (GSOC) through the MGDS to the Project. Prior to launch, GDS tests were conducted to demonstrate data flow from the Shuttle system through the MCCC to the Project. Even during times of infrequent Project changes, Betty continues to test new multimission support capabilities introduced by the DSN or MOSO. For example, the DSN had significantly upgraded their computer capabilities to prepare for the launch of Mars Observer. Although there are no new capabilities for Galileo, Betty participates in Multimission Verification Tests to ensure that the new software will support Galileo. She also conducts GDS tests prior to such major mission events as Gaspra and Earth encounters.

Planning and conducting MOS training and operations readiness exercises is the job of Galileo MOS Test and Training Engineer Larry Bryant. Most training on Galileo is the responsibility of the individual teams and offices, but when an exercise involving the entire Flight Team is necessary, Larry steps in to plan and conduct it. This type of exercise usually occurs prior to a major mission milestone, such as launch, or prior

to a significant change in new support capabilities. For example, Larry is currently working on defining and coordinating the training needed to transition the Flight Team to the new MGDS data system capabilities.

Tina Walker, Ed Garcia, and Pat Laubert, the Configuration Management Support Staff, maintain the configuration baseline for Galileo. One of their tasks is to coordinate and run the Project Change Board (PCB). The PCB consists of the Project Manager, Mission Director, and Office Managers, who meet regularly to consider changes to the Galileo support configuration. These changes include Sequence Change Proposals, Software Change Requests, Project Change Directives (documentation changes), and waivers to Mission and Flight Rules. Tina, Ed, and Pat also maintain the databases and Level 5 software development schedules for the Project.

Documentation changes usually involve updates to the Project documentation, and it is Georgia Stuffelbeam who updates the documents, coordinates final drafts with the requester, and manages the final distribution. Examples of documents regularly updated by Georgia include Software Requirements Documents, User Guides, Software Interface Specifications, and Team Operations Plans. She also maintains the Project computer equipment inventory and the team interface database. Frederick Melikian, an academic part-time employee at JPL and a Glendale College student, assists Georgia. He has considerable computer and word-processing expertise and is frequently able to help the people in the Project Office.

In addition to managing the GSO, John McKinney also performs GDS and MOS engineering duties. As GDS Engineer, John defines Project support requirements and coordinates the development and implementation of ground system capabilities with the Project, DSN, GSOC, and MOSO. He represents the MOS in Galileo low-gain antenna studies, coordinates the conversion to the new MGDS being developed by MOSO, and works with GSOC to coordinate the start of cruise science support after deployment of the High-Gain Antenna. In addition to his many and varied Galileo duties, John also supervises the Ground Data System Engineering Group in Section 317.

John grew up in the small town of Crane, Texas, and attended Texas A&M University, where he earned his master's degree in mathematics and computer science in 1967. After college (which included ROTC), he signed up with the Air Force and was assigned to the Air Force Satellite Control Center in El Segundo, California. Soon after his arrival in California, he met and married Eileen, who was then working as an executive secretary and administrative assistant. In 1971, after leaving the Air Force, John pursued his lifelong interest in space exploration by applying for a job at JPL. He was hired by none other than Galileo Mission Director Neal Ausman to oversee the development and operations of the Sequence Events Generator Program for the Mariner '71 Project. Then the Mariner–Venus Project beckoned, and John supported the MOS design and served as a mission controller during operations. After Mercury encounter, John moved on to the Voyager Project to serve as the Mission Sequence System Engineer. Finally, in 1978, he joined the Galileo Project as GDS System Engineer, eventually to become the GSO Manager.

Eileen and John have two sons, Michael and Matthew. Michael graduated from the University of California at Irvine in June and is now enrolled in graduate school at USC. Matthew, an avid follower of the exploits of the crew of the Starship *Enterprise*, is a third grader at Stowers Elementary School in Cerritos. The McKinneys are active in the PTA (Eileen is a PTA board member), Cub Scouts (Eileen is a Den Leader and John is Pack Treasurer), City League baseball, and soccer. Somehow they also find time to be active members of the JPL Amateur Radio Club as well—John is a past treasurer and president and Eileen has edited the club's newsletter for the last 11 years. It seems that John is working 24 hours a day, and even many of his leisure activities are extensions of his JPL work. He spends a lot of time at his home computer, and on Saturday mornings he teaches programming to seventh and eighth graders at a school near his home. In addition, his trips to Germany to coordinate GSOC support and a passion for classical music have led John to become something of a Mozart fanatic. And, while he reads technical books "just for fun," during last year's 200th celebration of Mozart's death he turned to reading various biographies of the composer. When time permits, John also enjoys fishing and has made several deep-sea fishing expeditions with his son Michael.

From the Project Manager (continued from page 1)

at any time since then. Three weeks after EGA2, in the last week of December, we will have the first opportunity to restore the HGA to assembly dimensions. Galileo will be 1.0 AU from the Sun, where a warming turn will expand the tower to assembly length for the first time. While considered unlikely, it is possible that this action alone will free the ribs.

"Hammering" the deployment system is our very best prospect to free the ribs. While performing investigative testing on the flight spare HGA at JPL early this year, it was discovered that pulsing the deploy motors rotated the deployment ballscrew substantially beyond its continuous run stall point. Following the extension of the tower, we will hammer the ballscrew as far as it will rotate by pulsing the motors. During the April 1991 deploy attempt, the ballscrew stalled at 5.1 turns. Our recent ground tests and motor pulse test on the spacecraft indicate we can advance the ballscrew 1.5 turns by a combination of running the motors continuously at warm temperatures (windup) followed by about 1000 pulses. This will double the force in the highest loaded rib deploy pushrod. There is a good chance that before reaching the new hammer stall point, the rising force in the pushrod will overcome the rib restraint and pop the rib free. The dynamic effect on the deployment mechanism of this rib springing out could free the other ribs. If this "zipper" action does not occur, then we will resume hammering the now softer system. This will increase the force in the remaining stuck rib pushrods by several factors. The hammering technique has the prospect of actually yielding (permanently deforming) any stuck pins and receptacle surfaces.

While the prospects of freeing the HGA by the above method are good, we must be prepared for the possibility that the ribs will remain stuck. Earlier this year, the Project, in conjunction with the Telecommunications and Data Acquisition (TDA) organization at JPL, studied how to maximize the mission return over the Low-Gain Antenna (LGA). We have always known we could perform the atmospheric entry Probe mission and put the Orbiter into Jupiter orbit without the HGA. The challenge was to return Orbiter science, particularly imaging, over the LGA. The joint Galileo and TDA study determined that improvements in the Deep Space Network (DSN) antennas and arraying of antennas in conjunction with data compression on board the Galileo spacecraft would enable the return of a tape recorder load of data each Jupiter orbit. Each tape load could contain 200 to 400 images, as well as data from all the other lower rate instruments. So, in our primary 10-orbit mission, we could return 2000 to 4000 images. Most of these would be the high-resolution satellite images that have always been a very special feature of the Galileo mission. Fields and particles data would be returned nearly continuously at low rates. Our overall estimated science return for the LGA mission in percentages of the primary HGA mission breaks down as: atmospheric science, 80%; satellite science, 70%; and magnetospheric science, 60%. NASA Headquarters has accepted our recommendation that we proceed with the implementation of the LGA mission on March 1, 1993, if the HGA is not deployed by then. The implementation will include new DSN hardware and software and major new flight software for the Galileo Command and Data Subsystem (CDS) and Attitude and Articulation Control Subystem (AACS). With or without the HGA, Galileo will be a spectacular mission at Jupiter!

Finally, I am very pleased that an excellent Jupiter satellite tour was designed and selected on schedule, May 1, and, concomitant with the selection, the Project recommended and NASA enthusiastically approved the August 1993 asteroid Ida encounter.

—*Bill O'Neil*

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The Galileo Messenger

Issue 31 **February 1993**

From the Project Manager

On to Jupiter! VEEGA is complete. The sole purpose of our 3.2-year VEEGA trip—over twice around the inner solar system and 10 months in the asteroid belt—was to get Galileo onto a direct Earth-to-Jupiter trajectory. Did we ever! The "injection" provided by the Earth 2 gravity assist (EGA2) on December 8 was essentially perfect. Galileo flew within one kilometer of its aimpoint, which was 304 kilometers above the South Atlantic Ocean at 34°S, 6°W. Because the navigation was so accurate, the first post-Earth 2 maneuver (TCM 18) was cancelled. About five kilograms of propellant were saved for our Jupiter mission.

Along the VEEGA trajectory, we collected a bounty of science of opportunity. Significant new data were collected on Venus' atmosphere and its surrounding environment; the Near-Infrared Mapping Spectrometer even imaged the *surface* with *emission* spectroscopy. At Earth 1, excellent observations were made of the far side of the Moon and of Antarctica. Also, for the first time, a color movie was created of the Earth making a full 24-hour rotation on its axis as a globe in space. Then, on October 29, 1991, Galileo was the first spacecraft to encounter an asteroid, 951 Gaspra; it was an outstanding

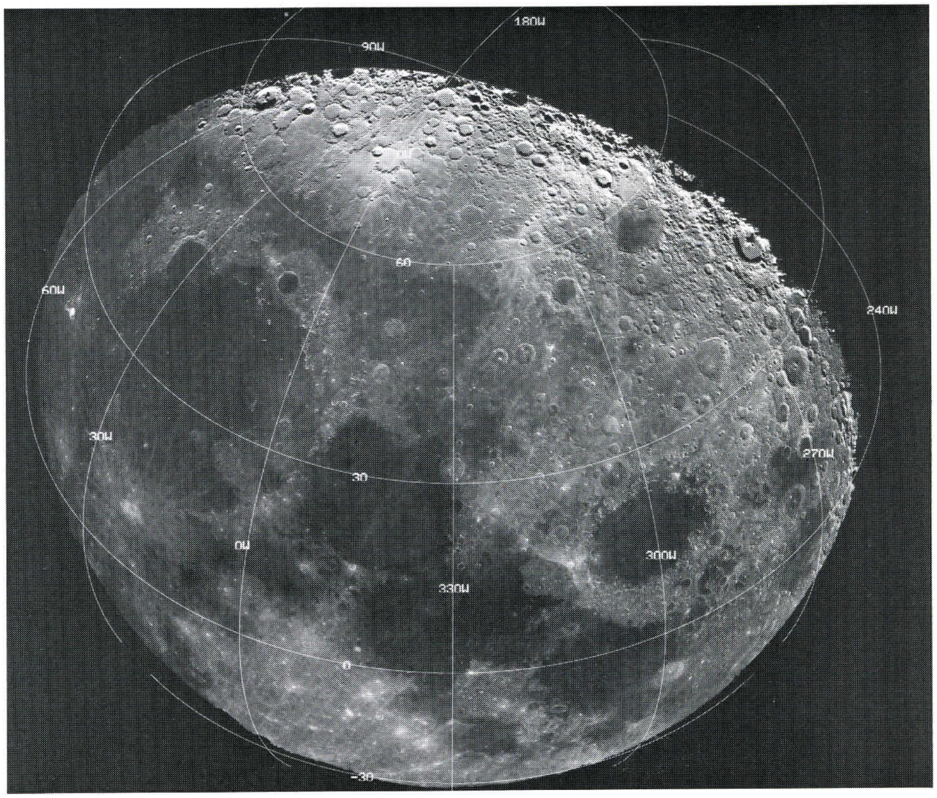
—see page 9

Observing the Moon in a Different Light

Story on page 2

The viewing geometry afforded by Galileo's flight over the north pole and the low-angle illumination provide a unique opportunity to assess the geologic relationships among the smooth plains, cratered terrain, and impact ejecta deposits in the north polar region of the Moon. In this image of that region, the north pole is to the lower right. The view in the upper left is across the volcanic lava plains of Mare Imbrium. The prominent crater with the central peak is Pythagoras, an impact crater some 130 kilometers in diameter. The image suggests that these and other impacts on the Moon have exposed lava flows more than 3 billion years old. The size of the flows indicates that the Moon had more frequent and extensive volcanic disturbances during its youth than previously suspected. The image was taken 121,000 kilometers from the Moon through the violet filter of Galileo's imaging system. (P 41432)

Observing the Moon in a Different Light



This mosaic of the Moon was compiled from 18 images taken by Galileo some 11 hours before its closest approach to Earth. This image shows the north polar region (near the top), Mare Imbrium (the dark area on the left), Mare Serenitatis (center), and Mare Crisium (the dark circular area to the right). Bright crater rim and ray deposits are from Copernicus, an impact crater 96 kilometers in diameter, at the far left of the image. Computer processing has exaggerated the brightness of poorly illuminated features near the day–night terminator in the polar regions, giving a false impression that the surface there is highly reflective. The digital image processing was performed by Deutsche Forschungsanstalt für Luft- und Raumfahrt (DLR), the German aerospace research establishment, an international collaborator in the Galileo mission. (P 41475)

In 1973, Mariner 10 photographed the north polar region of the Moon. Almost 20 years later, Galileo revisited this area, imaging the region for the first time in infrared color and providing new information about the distribution of minerals on the lunar surface. Traveling at over 48,000 kilometers per hour on its way to receiving its last gravity assist at Earth, the spacecraft flew within 110,000 kilometers of the Moon. The Project's goals for the December 7, 1992, flyby included obtaining multispectral lunar images, calibrating Galileo's instruments by comparing their data to those of previous lunar missions, and getting additional baselines for comparing our Moon with the Jovian satellites Galileo will be exploring beginning in 1995.

Galileo imaged the Moon's north pole at several different wavelengths (including infrared wavelengths beyond the range of human vision), a feat never before accomplished. The best of Galileo's images had a resolution of 1.1 kilometers/pixel and were three times the resolution the spacecraft had obtained at its previous lunar flyby. Scientists found evidence that the Moon has been more volcanically active than researchers thought.

The Near-Infrared Mapping Spectrometer (NIMS) imaged the polar region in 204 wavelengths, another first in lunar mapping. These images indicate there is more pyroxene (containing magnesium, iron, and calcium) and olivine (containing magnesium and iron) in the maria than in the highlands. (Maria, or lunar seas, are the large, flat, dark areas on the Moon.) While scientists knew of this compositional difference between the maria and the highlands, "we did not know how to characterize the region near the north pole," pointed out NIMS Principal Investigator Dr. Robert Carlson. "We now know that some of the smooth areas in the polar regions are like the maria."

The spacecraft also collected spectral data for dark mantle deposits (areas of local explosive volcanic eruptions). These maria deposits are more spectrally, and therefore more compositionally, diverse toward the near side of the Moon. Specifically, scientists discovered that titanium is present in low to intermediate amounts toward the far side, suggesting that the far side has a thicker crust. This type of spectral data also allows scientists to determine the sequence of meteoric impacts and the thickness of ancient lava flows.

In observing the features of the Imbrium impact basin on the near side of the Moon, the imaging

team was surprised to find some hidden maria. These "cryptomaria" are overlain by other features, and can only be seen in special spectral bands. "Nearly 4 billion years ago, the impact in the Imbrium basin threw out a tremendous amount of rock and debris that blanketed the Moon and caused erosion of the highland terrain. The blanketing and sculpture are seen in these images of the north pole," noted Dr. Ron Greeley, Arizona State University, a member of the imaging team. The presence of these cryptomaria extends the previously accepted age and extent of lunar volcanism.

In part, the measurements of the Moon were made to confirm that Galileo's instruments are working properly. Scientists examined information from earlier American and Soviet lunar missions, including actual soil and rock samples brought back from the Apollo 16 and 17 missions. These missions, based mainly in Mare Tranquillitatis and Mare Crisium, discovered a large amount of titanium in the soil. Scientists also compared the data Galileo had gathered at its previous flyby of the Moon in December 1990. All the instruments are indeed working properly.

Galileo's images of the Moon are similar in resolution to the pictures the Voyager spacecraft took of Jupiter's moons. However, when Galileo reaches Jupiter, it will be ten, a hundred, even a thousand times closer to Jupiter's moons than Voyager was. This means that Galileo's images of the Jovian moons will have a resolution up to a thousand times better than that seen in these pictures of our Moon.

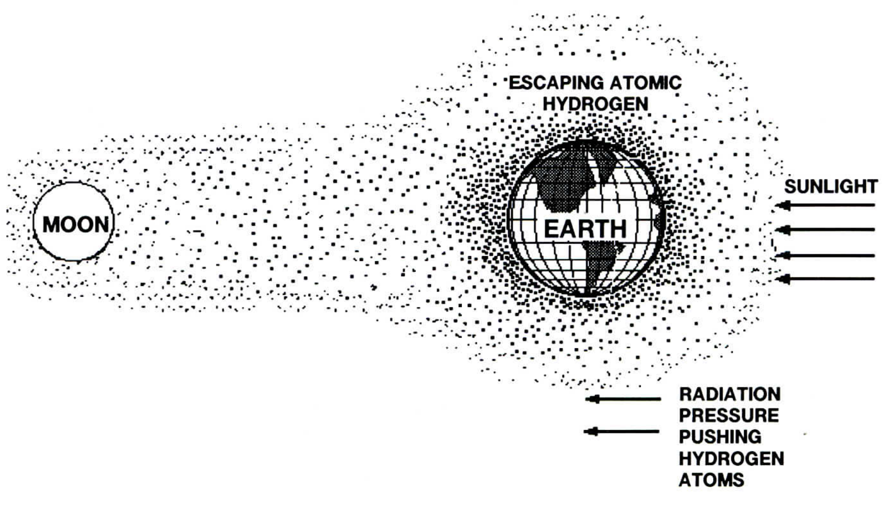
A Farewell to Earth

Galileo bid adieu to the Earth on December 8, 1992, at 7:09 A.M. PST. The spacecraft swept within 303.1 kilometers of the South Atlantic Ocean, its point of closest approach to the Earth. This, the last of three planetary gravity assists, added 3.7 kilometers per second to the spacecraft's speed in its solar orbit. In addition, the gravity assist changed the spacecraft's direction slightly, so its elliptical orbit will intersect the orbit of Jupiter, about 780 million kilometers from the Sun. The navigation, as in previous gravity assists, was impeccable. Galileo was within a kilometer of its intended path, and was just 0.1 second early.

The gravity assist was the essential item on the Project's agenda at this latest Earth flyby. However, with a constant eye to gleaning knowledge from every opportunity, the Project planned several scientific investigations during this flyby. Much of the analysis of these investigations continues, but initial results have been announced by the Near-Infrared Mapping Spectrometer (NIMS) and Ultraviolet Spectrometer (UVS) teams.

During the first Earth flyby, in December 1990, the NIMS instrument observed stratospheric clouds over Antarctica. Scientists now know that these clouds play a significant role in the complex sequence of events leading to the formation of an ozone hole over the South Pole. The extreme cold in the Antarctic stratosphere during the winter produces clouds composed of ice crystals rather than water droplets. On the surfaces of these ice crystals, reactions occur that result in the release of large amounts of ozone-destroying chlorine. The arrival of the Sun in the Antarctic spring triggers photochemical processes, resulting in the dramatic depletion of stratospheric ozone. As the ozone hole comes and goes each year, it appears to be growing larger. This trend follows the increase in chlorine released into the atmosphere through industrial activity.

At the time of the first Earth flyby, scientists were surprised to find stratospheric clouds. Galileo's NIMS instrument again found these clouds at the second Earth flyby. The clouds consist of large (20-micron) ice crystals and cover a large geographic area. What had



As the atomic hydrogen in the geocorona is exposed to sunlight, the hydrogen emits radiation. The pressure of this emitted Lyman-alpha radiation sweeps much of the hydrogen away from the direction of the Sun, creating a geotail.

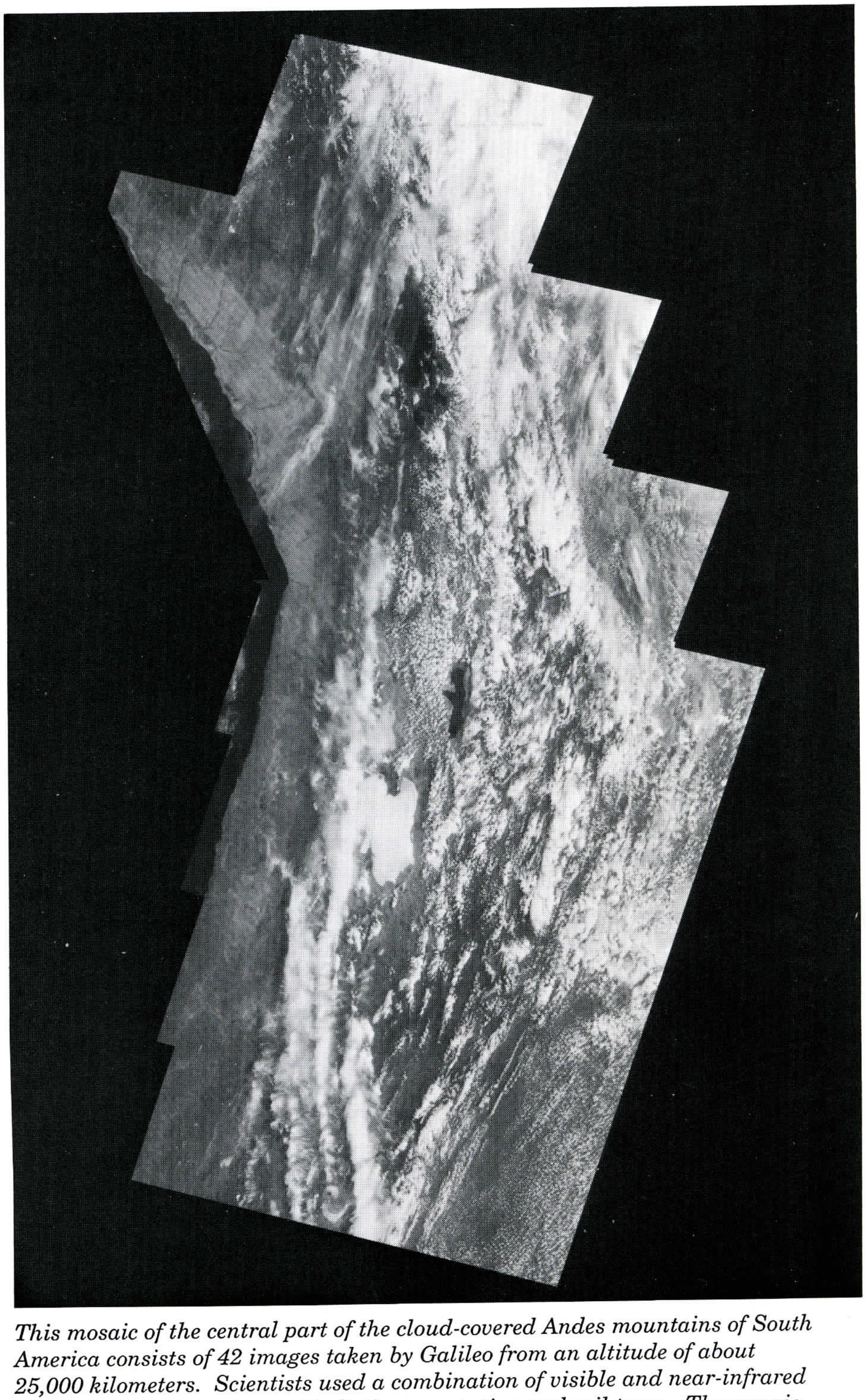
been hoped to be an anomaly is now suspected to occur more frequently. Dr. Robert Carlson, Principal Investigator for NIMS, notes, "We have good evidence for these high stratospheric clouds, which may have been elusive before. These clouds may be a common phenomenon over Antarctica."

Along with the NIMS team, the UVS team, led by Principal Investigator Dr. Charles Hord of the University of Colorado, discovered a wealth of information about the Earth's corona, the geocorona.

The geocorona is the outermost part of the Earth's atmosphere and consists of hydrogen that has escaped (or "evaporated") from the Earth's mesosphere. This atomic hydrogen, when exposed to the Lyman-α radiation of the Sun, absorbs and re-emits this radiation. (Lyman-α radiation occurs at a wavelength of 121.5 nanometers.) This absorption process leads to a force on the hydrogen atom in the anti-Sun or geotail direction. The atomic hydrogen in the geocorona and geotail scatters the Lyman-α radiation from the Sun, and some of this scattered radiation is then detected by Galileo's UVS.

During this Earth flyby, Galileo's UVS conducted 11 scans of the space around the Earth and Moon. The geocorona had previously been measured at its geotail to distances of 95,000 kilometers. Galileo detected a huge hydrogen corona bulge surrounding the Earth to approximately 400,000 kilometers at the geotail, nearly to the Moon's orbit and four times the thickness of the traditional geocorona model. In fact, Galileo actually detected atomic hydrogen near the Moon at a level of approximately 1 atom/cm^3. The UVS team currently believes all or most of this hydrogen is associated with the extension of the Earth's geocorona, rather than an aspect of the Moon's tenuous atmosphere.

The NIMS and UVS will continue their studies of planetary atmospheres when Galileo reaches Jupiter in December 1995.



This mosaic of the central part of the cloud-covered Andes mountains of South America consists of 42 images taken by Galileo from an altitude of about 25,000 kilometers. Scientists used a combination of visible and near-infrared filters to separate regions with distinct vegetation and soil types. The mosaic shows the area where Chile, Peru, and Bolivia meet; the Pacific Coast appears to the left. Lakes Titicaca and Poopo are nearly black patches top and middle, respectively; a large light area below and left of Lake Poopo is Salar de Uyuni, a dry salt lake some 120 kilometers across. These lakes lie in the Altiplano, a region between the western and eastern Andes. The vegetated Gran Chaco plains east of the Andes are a lighter shade than the Altiplano. Pale patches in the mountains to the north are glaciers. (P 41493)

Gaspra's Story Continues

Scientists continue to analyze the data received from Galileo's historic encounter with an asteroid. Although Galileo flew past asteroid Gaspra on October 29, 1991, because of the limited data transmission rate, the Project only received the bulk of the Gaspra information in November 1992. The images reveal Gaspra to have a cratered surface and irregularly shaped body about 19 by 12 by 11 kilometers. The spacecraft passed about 1600 kilometers from Gaspra at a relative speed of about 8 kilometers per second.

The recent data from Gaspra suggested that the asteroid may have a magnetic field. This evidence is based on the behavior of the solar wind, an ionized stream of gas that flows out from the Sun at two million kilometers an hour and carries a magnetic field. The solar wind field changed direction a few hundred kilometers from the asteroid, as if it had slammed into a magnetic region. This change in direction is known as a field rotation. Galileo again detected a field rotation shortly after closest approach. "At the present time, we cannot be sure these field rotations were produced by the interaction with Gaspra," emphasized Dr. Margaret Kivelson, of U.C.L.A. and the Principal Investigator for the Magnetometer. "Field rotations are a common feature of the solar wind and their association with Gaspra may be fortuitous. Our conclusions are highly speculative, but extremely plausible.

"One of the big puzzles is understanding the processes that account for the properties of the diverse planet-like asteroids that appear between Mars and Jupiter (in the asteroid belt)," Kivelson continued. "Their composition is thought to be related to that of meteorites. *If* Gaspra has a permanent magnetic moment, the finding would have bearing on its thermal history, have implications for the history of the magnetic field of the early solar system, and give us more reason to believe some asteroids are very rich in iron or iron-nickel alloys of considerable economic value."

To have caused these field rotations, scientists believe Galileo passed through a magnetic wake, like the wake caused by a ship or a bullet in flight. The angle that this wake sweeps back depends not only on the size of the obstacle (the asteroid), but also on the properties of the medium (interplanetary plasma) and the kind of waves that can propagate in it. For plasma physicists, one aspect of interest here is that the Gaspra wake may present a rare example of waves carried by a "whistler wing." This phenomenon has never been observed outside the laboratory, but the actual results closely follow what was predicted from laboratory results.

Scientists are intrigued that Gaspra's magnetic field appears to resemble the fields measured in some meteorites. Galileo's August 28, 1993, encounter with asteroid Ida may help to understand these results. Like Gaspra, Ida's composition is believed to be representative of a major class of main-belt asteroids. However, the two asteroids' compositions should differ somewhat.

This montage shows asteroid Gaspra (top) compared with Deimos (lower left) and Phobos (lower right), the moons of Mars. The three bodies are shown at the same scale and under nearly the same lighting conditions. Gaspra is about 17 kilometers long. All three bodies have irregular shapes, due to past catastrophic events. However, their surfaces appear remarkably dissimilar, possibly because of differences in composition, but most likely because of very different impact histories. The Phobos and Deimos images were obtained by the Viking Orbiter in 1977; the Gaspra image is the best obtained by Galileo on October 29, 1991. (P 41382)

Up To Date

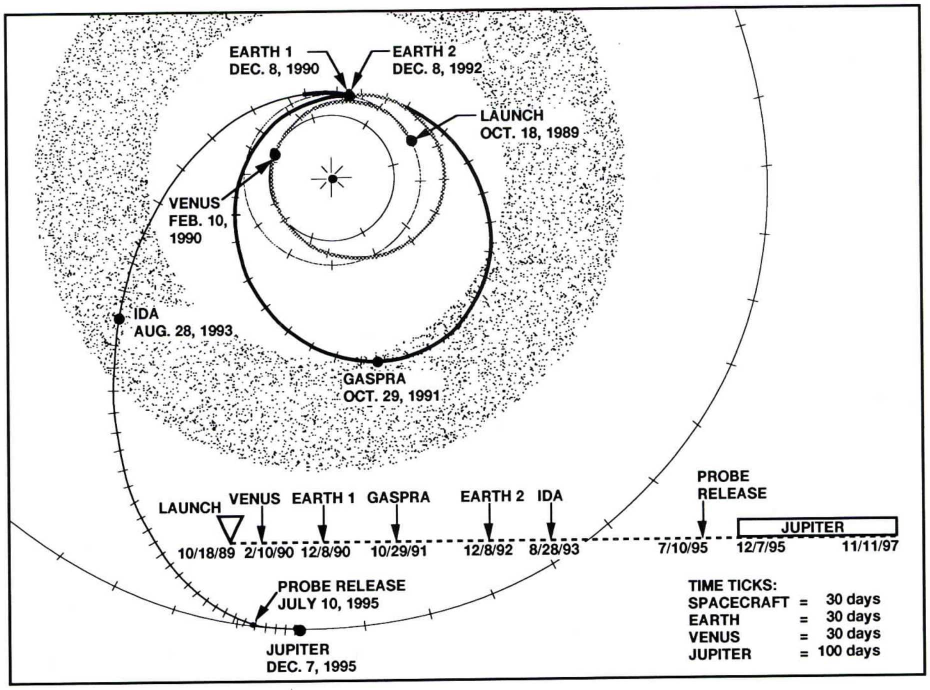
Operations Activity Summary

During this update time period, the spacecraft performed many operations, including attitude maintenance SITURNs, 10-newton thruster flushes, Trajectory Correction Maneuvers (TCMs), and power management activities. Additionally, the Low-Gain Antenna 2 (LGA-2) was retracted and several High-Gain Antenna (HGA) motor-related calibration and characterization activities were performed. While Galileo was near the Earth, the LGA-1 telecommunications performance permitted two Probe checkouts, the return of all of the Gaspra and Earth 2 encounter data, a host of science and engineering calibrations, the Galileo Optical Experiment (GOPEX), and intensive HGA motor hammer activities from December 29, 1992, through January 19, 1993.

Attitude Control

Ten SITURN attitude maintenance maneuvers were performed. In addition, three special HGA-related warming turns were accomplished to warm the HGA deployment motor and characterize the spacecraft thermal response in support of planned HGA motor hammer operations. The spacecraft performance throughout these turn activities was normal.

During the approach to Earth, four TCMs occurred, namely, TCM 14, TCM 15, TCM 16, and TCM 17. The delta velocities imparted by these maneuvers were 21, 0.7, 0.9, and 0.03 meters/second for TCMs 14 through 17, respectively. The final TCM was performed on November 28, as planned, 10 days before Earth flyby. The spacecraft performance throughout these maneuvers was generally normal and as expected.



Galileo's trajectory—on toward Jupiter.

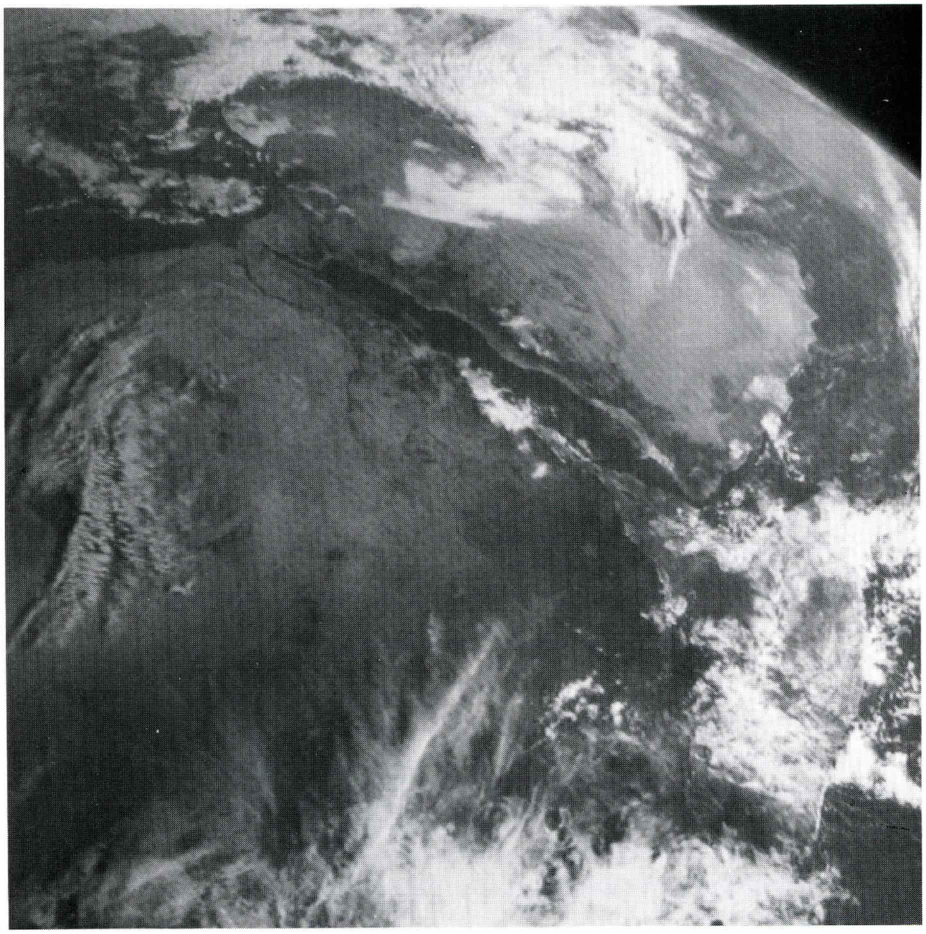
Calibration and Characterization Activities

During the past few months while near the Earth, numerous science instrument and engineering calibration and characterization activities were performed to take advantage of the high telemetry data rates achieved while the spacecraft was close to the Earth. The Magnetometer instrument underwent calibration using the external calibration coil and completed a scan platform interference test. The Scan Actuator Subassembly completed a friction test, and the Plasma Wave Subsystem conducted calibration activities. The Near-Infrared Mapping Spectrometer performed calibrations using the photometric calibration target (PCT), the radiometric calibration target, and the mirror scan. The Ultraviolet Spectrometer (UVS) star and radiometric calibrations were conducted. The Solid State Imaging (SSI) subsystem completed star calibrations, a PCT calibration, and a boomscatter test. Finally, the Extreme Ultraviolet Spectrometer completed a cross-calibration activity with the UVS. All activities were performed nominally and the data are being analyzed.

Probe Checkout

On November 20, the first inflight Probe Mission Sequence Test thoroughly tested all of the Probe's scientific instruments and the actual Probe mission sequence. Post-test analysis by Hughes Aircraft Corporation, Ames Research Center, and science personnel concluded the Probe and its scientific instruments are operating nominally. On December 2, the newly generated Probe Abbreviated System Functional Test was performed. This test is a significantly scaled-down version of the System Functional Test and, basically, checked the battery voltages and expelled any unwanted argon gas from the Neutral Mass Spectrometer instrument.

In support of the planned Probe checkouts, Probe Mission Readiness/Ground Data System Tests



This image of Northeast Africa and Arabia was taken from an altitude of about 500,000 kilometers by Galileo on December 9, 1992. Most of Egypt (center left), including the Nile Valley, the Red Sea (slightly above center), Israel, Jordan, and the Arabian Peninsula are cloud-free. In the center, below the cloud on the coast, is Khartoum, at the confluence of the Blue Nile and the White Nile. Somalia (lower right) is partly covered with clouds. (P 41474)

were successfully conducted on October 18 and 26 with the Deep Space Network (DSN) Signal-Processing Center (SPC) 60. Probe data were routed through the DSN station processors to the Galileo Mission Control and Computing Center (MCCC) Telemetry Subsystem, where the data were processed, displayed, and routed to the Probe Flight Operations Equipment in real time.

High-Gain Antenna Motor Activities

In preparation for the planned HGA Dual-Drive actuator (DDA) motor hammer activities near 1 AU, special activities were performed in July, September, and October to calibrate and characterize the HGA deployment system and characterize the spacecraft thermal response at a 45-degree off-Sun attitude.

In July and September, the DDA deployment motors were powered on for 1.87 seconds to collect motor current at different temperatures. In October, after the spacecraft was turned 45 degrees off-Sun for about 48 hours, the deployment motors were pulsed on and off 10 times using a special hammer control routine developed by the CDS. During the October activity, the motor current measured less than the stall current, indicating that some ballscrew rotation probably occurred. Although the sun gate field of view was still obscured, data revealed some small change (less than a degree) in the rib number 2 deploy angle.

After the Earth encounter, the Project attempted to unfurl the antenna by intensive hammering of the HGA motors. On December 29, after approximately 20 hours at the 45-degree warming attitude, hammering activities were performed. A total of 2160 hammer pulses were executed along with three 20-second windup sequences. Motor-current data indicated the ballscrew rotated somewhat more than 360 degrees (consistent with ground test results) for a total ballscrew rotation beginning with the initial deployment attempt (in April 1991) of approximately 6.4 rotations. There was no indication of rib release, although rib number 2 moved out to 43 degrees from its pre-hammer position of about 37 degrees. The sun gate's field of view was still obscured, although the signature was different from earlier data. The spacecraft wobble data indicated a small change of 0.3 milliradian, which corroborated the motor-current data suggesting that the HGA configuration had changed, but that no ribs had released.

Additional hammering activities occurred on 11 days in early to mid-January. These pulse sequences consisted of eighteen 180-pulse and twenty-two 360-pulse hammer sequences. At the end of the January 19 hammer action, a total of 13,320 motor pulses had been accumulated. During these hammer activities, the HGA motor temperature ranged from 5.2° to 52°C. Each pulse in the train applied power for about 0.25 second, using a 33.3 percent (1.25 hertz) or 50 percent (1.875 hertz) duty cycle. No substantial rotation has been observed since the major hammering on December 29, 1992.

Galileo Mission Summary*

Distance from the Earth	36,574,100 kilometers
Distance from the Sun	176,192,200 kilometers
Distance from Jupiter	711,152,400 kilometers
Round-Trip Light Time	4 minutes, 6 seconds
Velocity Relative to the Sun	125,900 kilometers per hour
Spacecraft–Sun Angle	7° off Sun
Spacecraft Spin Rate	2.89 revolutions per minute
Spin Configuration	All spin
Downlink Telemetry Rate	1200 bits per second, coded (Low-Gain Antenna 1)
Powered Science Instruments	Dust Detector Subsystem, Energetic Particles Detector, Extreme Ultraviolet Spectrometer, Heavy Ion Counter, Magnetometer, and Plasma Wave Spectrometer
General Thermal Control	All temperatures within acceptable ranges
RTG Power Output	518 watts
Real-Time Commands Sent	64,758 commands

*All information is as of January 28, 1993.

Anomaly Status

UVS Memory

In early November, when low-rate science telemetry was available, engineering telemetry from the UVS indicated four unexpected instrument readings. Immediate analysis by science and engineering personnel concluded the unexpected readings did not pose a threat to the instrument. Subsequent diagnostic memory readouts verified the anomaly. The UVS was powered off at the request of the Principal Investigator. Ground simulations at the University of Colorado recreated the flight anomaly and demonstrated that all the unexpected readings could be caused by a *single* memory bit flip. This is the first memory-related anomaly observed in three years of flight. The cause for the bit flip is unknown, but may be due to read-disturb, electrical-noise sensitivity or a weak oxide in the TCC 244 memory chip; analysis of this anomaly is in process. After further analysis and consultation, the UVS was repowered and successfully configured and functioned properly throughout the Earth encounter.

Near-Earth Downlink

Shortly after the Earth flyby and for several days thereafter, downlink radio frequency signal strength variations of about 6 decibels were observed from the spacecraft. These variations caused the telemetry link to be intermittent. Analysis concluded that the anomalous downlink was likely the result of spacecraft boom/structural interference created at the high telecommunication cone angles during the early part of the Earth flyby trajectory. Subsequently, when the telecommunication cone angles were reduced (by stored-sequence planned SITURNs), the downlink signal strength variations were diminished and totally disappeared when the telecommunications cone angle dropped below 90 degrees.

AC/DC Imbalance

During this period, the DC bus imbalance reading continued to change. The DC measurement has ranged from about 44 (4.7 volts) to 160 data numbers (DN) (18.9 volts), and now reads 151 DN (17.8 volts). The more stable AC measurement has ranged from 12 to 19 DN and now reads 18 DN (4.1 volts). Intermittently during the burn activities of TCMs 16 and 17, the DC imbalance reading changed and then returned to its previous value. There was no consistency as to when changes occurred, i.e., before, during, or after burns. All the imbalance measurement changes are consistent with the models developed by the AC/DC special anomaly team.

No spurious transient CDS power-on-reset (POR) events have occurred. In fact, the most recent spurious POR telemetry indication occurred on November 30, 1991, and the most recent CDS bus reset POR occurred on the CDS "A" on July 19, 1991.

Ground Data Systems

During the June 28, 1992, earthquake in Landers, California, the DSS-14 antenna subreflector support mechanism partially failed, damaging the subreflector and its control mechanism. All repairs were made quickly, resulting in no loss of Galileo data.

Galileo Earth 2 Ground Data System testing was conducted on October 6 and 13, with the Galileo D1.0 ground system utilizing the MCCC real-time systems and the DSN Canberra SPC 40. The test validated the successful integration of the DSN and MCCC systems with Galileo's D1.0 ground system, in support of the Earth 2 activities.

Sequence Generation

There was a large sequence generation effort from July 1992 through January 1993, involving: four TCMs; HGA special warming turn activities; and EE-7, EE-9, and EE-11 Earth approach- and encounter-related sequences. Additionally, a significant sequence generation effort (for the

DDA-5 set of sequences) was completed for the HGA motor hammer activities. Other sequence-generation efforts included sequence planning and development for the post-Earth EE-12 and Earth–Jupiter cruise EJ-1 sequence.

Software

Ground

The Unisys Level-41 Operating System testing is complete. During the testing, 1.9 million lines of code were validated. The Unisys 1100/91B Level-41 Operating System upgrade went on-line for operational support on September 4.

On November 23, the D1.0 software delivery process was completed. This large software delivery began in September and included 29 program sets implementing 75 Software Change Requests and correcting 181 Failure Reports.

The D2.0 software deliveries are complete. Fourteen program sets were delivered at the D2.0 mission build.

Flight

A major flight software effort was completed during this time. The AACS flight software Phase 12.0 successfully completed its acceptance test and delivery review on July 29. This delivery incorporates corrections to liens and provides modifications to support the March 1993 10.5-rpm pulsed-mode spin-up activity. AACS Phase 12.0 was loaded on the spacecraft in January 1993.

—Matt Landano
Deputy Mission Director

From the Project Manager

(continued from page 1)

success. Based on our early planning, it appears that Galileo's upcoming August 28 encounter with asteroid Ida can be made even better than the Gaspra encounter.

Five years ago, on December 2, 1987, Project Galileo presented the VEEGA plan at a press conference in Washington, DC. On that occasion we declared our intention to obtain spectacular, unprecedented observations of the north polar region of the Moon and the Earth–Moon conjunction movie. At Earth 2 we did exactly that in grand style. For over 15 years now, we have emphasized that Galileo will be the first spacecraft to send a probe directly into an outer planet's atmosphere and the first to orbit an outer planet. In less than three years, Galileo will do exactly that on December 7, 1995, using the Low-Gain Antenna (LGA).

We have not been able to free the stuck ribs of the High-Gain Antenna (HGA) and there is no longer any significant prospect of deploying the HGA. On the first day of our HGA hammering campaign, December 29, the hammering produced the predicted results. The ballscrew rotated another turn, doubling the deployment forces. Recall, we had no way of knowing whether doubling the forces would free the ribs—it did not. The ballscrew rotation was fully corroborated by the position of rib number 2, which is opposite the stuck ribs and is obscuring the sun gate. That rib rotated another 7 degrees to 43 degrees (nearly two-thirds of full deployment). Having restalled the deployment system without a rib release, we knew there was little prospect that further hammering would help. Nonetheless, we applied over 13,000 hammer pulses by the end of the campaign on January 19, concentrating the pulses at thermal transitions, hoping that the subtle thermally induced configuration changes might make a difference. It was to no avail. Failure of the hammering to free a rib only increases the likelihood that it is indeed the locating pins that are holding the ribs stuck. We simply have no way to overpower their restraining force.

We are now proceeding to implement the Galileo mission using the LGA. We are absolutely confident of achieving at least 70% of our primary objectives, including 100% of the atmospheric Probe mission and several thousand of the highest resolution Jupiter satellite images ever planned. All the instruments will make their most important observations, and we will monitor the Jupiter magnetosphere virtually continuously, albeit at a low data rate.

The success of Galileo without the HGA at Jupiter will be a technological triumph. Developing the extensive, new spacecraft flight software and ground software and hardware, including state-of-the-art enhancements in the Deep Space Network (DSN), is a big challenge to complete in just three years. The Project and the DSN are fully up to this challenge. Galileo will indeed fulfill its promise and be a magnificent mission at Jupiter.

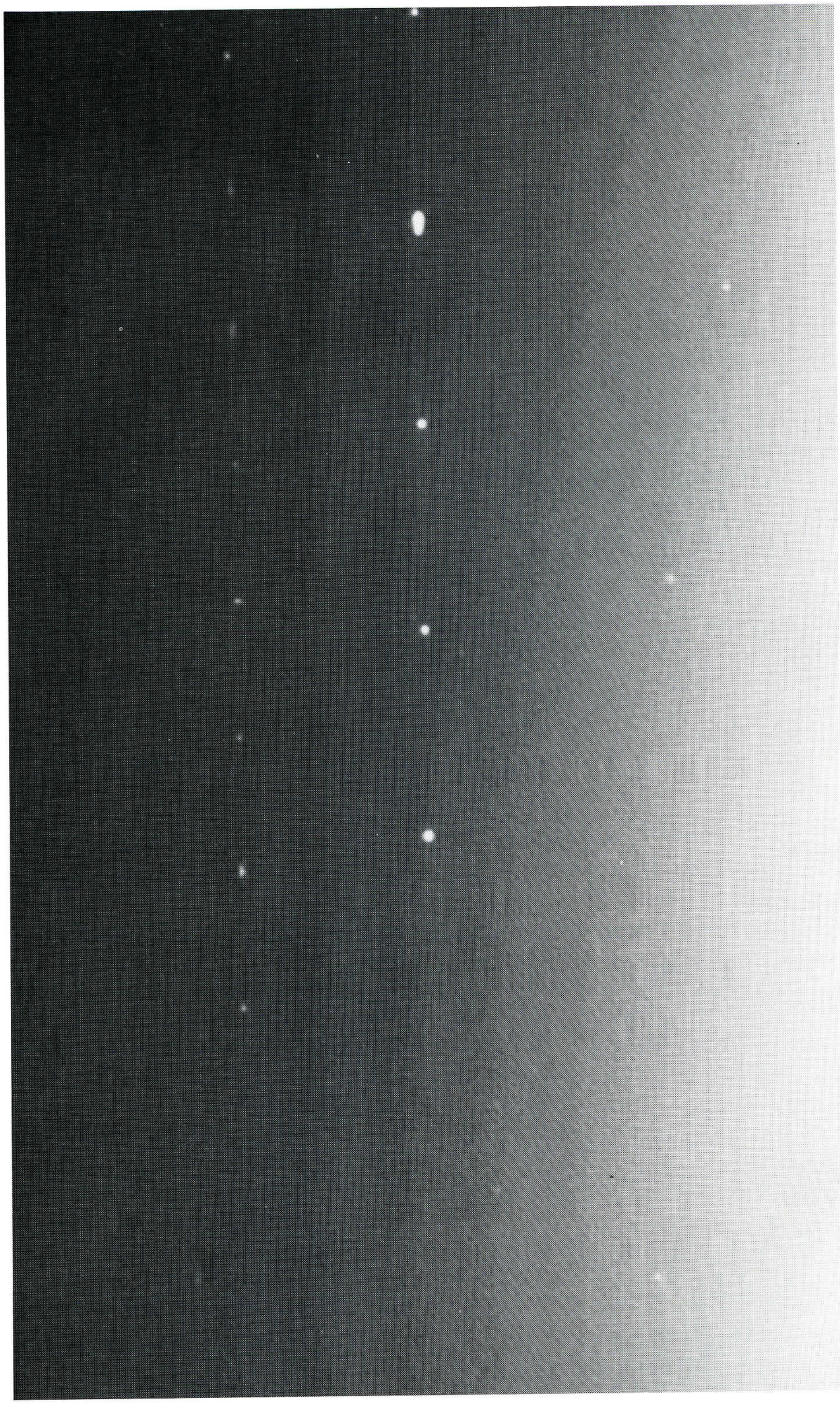
—Bill O'Neil

Communicating With Light

Engineers communicate with satellites via radio waves. Based on this fact, a large range of radio communications services is available, including the Deep Space Network with its array of large antennas distributed around the world. However, this basic tenet in satellite communication is now being questioned. Laser communications, faster and better than radio, may well be the wave of the future. The first step in implementing deep-space laser communications was taken with Galileo during last December's Earth encounter.

"Future deep-space missions can use laser beams to send back to Earth larger volumes of space-acquired data than are currently possible using radio signals," noted Dr. James Lesh, Principal Investigator for the Galileo Optical Experiment (GOPEX). "We will be able to handle more information since laser beams spread less than radio beams." In Galileo's case, GOPEX's laser beam (on the eighth day of the demonstration) spread to approximately 360 kilometers, whereas a radio beam would have spread to approximately 12,600 kilometers. Logically, if 20 watts of power were spread over a large area, the signal would be weaker than if that same amount of power were spread over a smaller area. Consequently, the tighter beamwidth of a laser yields a stronger signal for communicating. Laser beam communications will, therefore, lead to smaller transmitter–receiver apertures on future spacecraft.

GOPEX had three principal objectives: (1) to demonstrate laser-beam transmission to a spacecraft at deep-space distances; (2) to verify laser-beam-pointing strategies based solely on ground-based predictions of the



GOPEX's two sets of laser pulses, transmitted over a distance of 1.4 million kilometers, are shown in this long-exposure image. The sunlit part of the Earth (west central United States) is to the right, the night side to the left. The camera was scanned from the bottom to the top of the frame (approximately south to north), smearing terrain features, but showing individual pulses. The five larger spots in the vertical column near the center of the frame represent pulses from the Starfire Optical Range; those to the left are from Table Mountain Observatory. Spots near the day–night terminator to the right are extraneous noise. (P 41456)

*GOPEX consisted of pulsing a laser at the Galileo spacecraft from the Table Mountain Observatory and the Starfire Optical Range. The Galileo spacecraft successfully detected these laser beams. Above, the **actual** beam is seen emanating from Table Mountain Observatory. (P 41434A)*

spacecraft's location; and (3) to verify the performance of the optical link, rather than the radio link.

Table Mountain Observatory (TMO) in California and the U.S. Air Force Phillips Laboratory's Starfire Optical Range in New Mexico transmitted the GOPEX laser beams. The two laser transmitters each consisted of a frequency-doubled neodymium-yttrium laser (532 nanometers) coupled to a Cassegrain telescope. The TMO telescope was a 0.6-meter-diameter equatorial-mounted astronomical telescope. The Starfire telescope was a 1.5-meter elevation-over-azimuth mounted system.

Over the eight-day experiment, the spacecraft moved away from the Earth, from 600,000 kilometers on the morning of December 9 to 6,000,000 kilometers on the morning of December 16. In fact, on this final day, GOPEX's laser transmissions established a record for the farthest known transmission and reception of a laser beam. Scientists successfully detected the laser signals on each of the experiment days, although not on all frames within a given day. The lack of detections on all frames was due, in part, to poor weather at TMO and Starfire and restrictions imposed by the U.S. Space Defense Operations Center.

To produce the GOPEX images, Galileo's camera was scanned across the Earth, parallel to the Earth's terminator. The detected laser pulses from TMO and Starfire then appeared as a series of evenly spaced bright dots on the camera frame, quite distinct from other features. "We were very surprised by the consistency of observations, particularly considering that the atmosphere can cause a very large fluctuation in power—the same phenomenon that causes stars to twinkle," mentioned Lesh.

The success of the experiment heralds the way for optical communications in the twenty-first century. Dr. Keith Wilson, GOPEX Task Manager, noted, "Eventually, optical systems will replace the worldwide array of radio telescopes."

At a distance of 6.2 million kilometers, Galileo captured this view of the Moon orbiting the Earth on December 16, 1992. The Moon is in the foreground. The contrast for both objects has been enhanced. Antarctica is just visible through the clouds at the bottom of the Earth. The Moon's far side is seen; the shadowy indentation in the dawn terminator is the South Pole–Aitken Basin, one of the largest and oldest lunar impact features. As part of the Earth–Moon observations, Galileo created an Earth–Moon conjunction movie. This movie covered a 14-hour period showing the Moon passing by as the Earth slowly rotated beneath it. All of the data processing for this movie was conducted on the ground. (P 41508)

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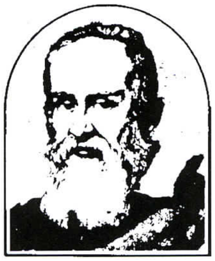

The Galileo Messenger

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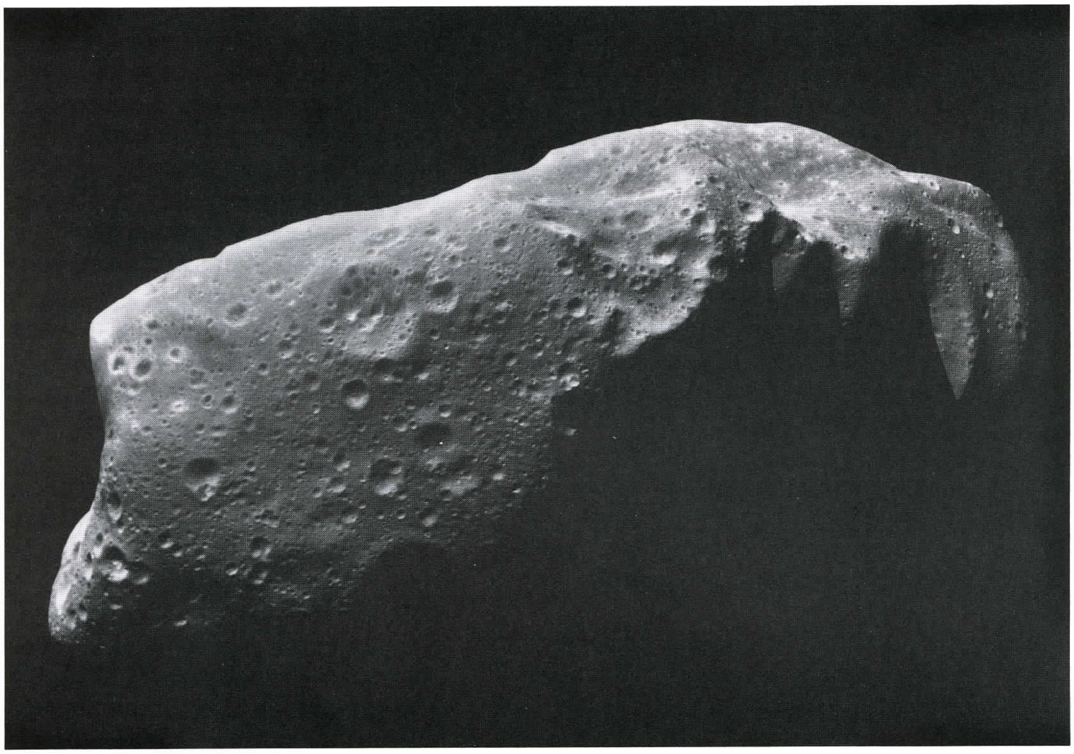


Ida Ho!

This mosaic of Ida consists of five image frames acquired by Galileo's Solid-State Imaging System at ranges of 3057 to 3821 kilometers on August 28, 1993, about 3-1/2 minutes before closest approach. Galileo flew about 2400 kilometers (1500 miles) from Ida at a relative velocity of 12.4 km/sec (28,000 mph). Asteroid and spacecraft were 441 million kilometers (274 million miles) from the Sun.

Ida is the second asteroid ever encountered by a spacecraft. It appears to be about 52 kilometers (32 miles) in length, more than twice as large as Gaspra, the first asteroid observed by Galileo in October 1991. Ida is an irregularly shaped asteroid, believed to be like stony or stony-iron meteorites, and is a member of the Koronis family, fragments left from the breakup of a larger asteroid in a catastrophic collision.

This view shows numerous craters, including many degraded craters larger than any seen on Gaspra. The extensive cratering seems to dispel theories about Ida's surface being geologically youthful. This view also seems to rule out the idea that Ida is a double body. The south pole is believed to be in the dark side near the middle of the asteroid.

The camera's clear filter was used to produce this extremely sharp picture. Spatial resolution is 31 to 38 meters (roughly 100 feet) per pixel. Playback of the remaining images is planned for April through June 1994. (P-42964)

From the Project Manager

Galileo's Ida encounter was a spectacular success. It was a lot tougher than it looked. A pair of spurious Command and Data Subsystem (CDS) bus resets occurred in June, after this phenomenon had been dormant for two years. Spin Bearing Assembly (SBA) brush lifts in the presence of otherwise benign brush debris shorts cause these random resets. Resets result in spacecraft safing, which terminates the spacecraft sequence. The Flight Team must then send and monitor the response of each of a half-dozen command packages to re-establish dual string (redundant) operation of the CDS and they must also build and uplink a new spacecraft sequence.

When a second pair of resets on July 10 and 12 precluded the first of five planned Ida optical navigation images, we began massive contingency efforts. Without at least two navigation images, the most important Ida observations might be missed due to degraded navigation. And, if a reset occurred within a few days of Ida, the whole encounter would be lost because spacecraft safing would terminate the sequence.

OpNav #2 was obtained without incident. Then, a fifth bus reset on August 11 precluded OpNav #3. The Flight Team had already very aggressively streamlined the recovery process. The Team quickly recovered the CDS, uplinked a prerequisite attitude maneuver, and executed the Ida –15 day TCM-20 exactly on schedule August 13—just two days after the reset!

At Ida –7 days, August 21, communication with the Mars Observer (MO) spacecraft was lost. Galileo and MO

were only 10 deg apart in the sky. Thus, maximum efforts to recover MO, requiring the 70-m DSN antenna at each complex, restricted Galileo tracking to a few hours a day during station view-period overlaps. OpNav #4 had been acquired without incident. The MO problem occurred 10 hours after OpNav #5 was shuttered, so only one-fourth of the image was returned.

The final navigation estimate, including OpNavs #4 and the partial #5, indicated Galileo was just 0.7 sec early and 10 km high—encounter would be at 16:51:59.0 UTC at 2410 km from Ida without performing TCM-21. Accordingly, at Ida –5 days, TCM-21 and contingency pointing updates were cancelled. The outstanding power and quality of OpNav #2 had enabled TCM-20 to hit the bull's-eye.

The Flight Team continued streamlining the recovery process for the Ida encounter and ultimately could have recovered from a reset as late as Ida –21 hours. Because a bus reset recovery was no longer possible, the last 21 hours were a period of anxiety to the max! At Ida –4 hours 16 minutes, a totally unrelated problem occurred. The spacecraft autonomously turned off its gyros and switched to cruise mode. The attitude control engineers quickly confirmed the encounter would be satisfactorily performed in cruise mode—scan-platform pointing controlled using only the encoders in the actuators. However, the mode change stowed the platform. A precisely timed ground command was sent at Ida –3 hours 18 minutes to restore proper pointing. Additional real-time commanding was required after closest approach to restore the configuration for subsequent sequence events. Gratefully, no bus resets occurred during the encounter—in fact, none have occurred since August 11. We have been operating Galileo in all-spin mode as much as possible since July 16 to minimize the reset threat, but the spacecraft had to be in dual-spin mode for the OpNav images, maneuvers, and the Ida encounter observing sequence.

As for Gaspra, the high resolution Ida image on the front page was obtained by copying about 150 lines of an imaging frame at a time into CDS memory and then transmitting that memory to the ground at 40 bps—the so-called DMSMRO. It takes about six DMSMROs to return a full frame. As luck would have it, Ida's location in the 30-frame-high resolution mosaic caused it to straddle 5 frames. Thus, nearly all of the available 35 DMSMROs in the September 40-bps playback opportunity were required to return this one image. The playback was further complicated when the Canberra 70-m antenna was down for six days due to a totally unprecedented transformer failure. Five unanticipated mini-mini-sequences had to be designed and uplinked to work around the outage.

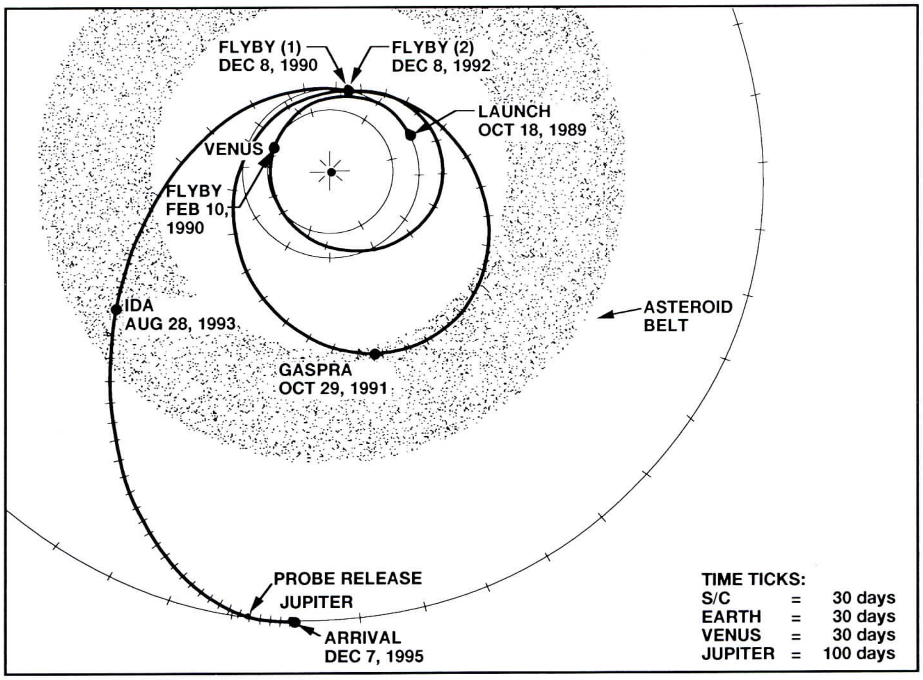
In summary, the Ida encounter took much, much more Flight Team effort than originally planned. The Flight Team, Deep Space Network, and Multimission Operations Systems Office did an outstanding job in the face of major difficulties. It was well worth it. The rest of the data will be returned next spring when the Earth's orbital position will again allow 40 bps.

For five days beginning October 4, Galileo will execute its largest 10-N maneuver. TCM-22 will impart 38.6 m/sec to Galileo to target the atmospheric-entry Probe to its entry corridor. It is noteworthy that this marks the first time the Galileo spacecraft has been targeted to Jupiter.

Excellent progress is being made developing the new capabilities for Jupiter. The Phase 1 software that provides a redundant Probe data path is already in test. The Phase 2 Orbital Operations requirements have been agreed upon with the Project Science Group (PSG) and the Flight Team, and the Preliminary Design Review (PDR) is on schedule for next month.

I am extremely proud of the achievements of the Galileo Project Team to date and confident they will perform an absolutely outstanding mission at Jupiter.

Bill O'Neil
Project Manager



The August 28 encounter with Ida was a major milestone on Galileo's trajectory to Jupiter.

Controlling the Spacecraft With the MCT

The Galileo Mission Control Team (MCT) members, highly professional, dedicated individuals, bring unique talents and skills to the complex task of mission plan execution. This combination of talents and skills provides a synergistic effect that benefits the Project. Functional interdependence and enthusiasm to get the operations job done right are the unique ingredients that make the MCT work.

The MCT is divided into two functional areas: real-time operations conducted by the Mission Controllers and real-time support under the auspices of the Ground Operations Engineer.

Real-time operations are conducted by four Mission Controllers (ACEs) (Gene Brower, Steve Hillabrand, Herlen Reed, Jr., and Ron Sharp) and a Data Technician (Kathy Fimbres), who are "on-line" whenever the spacecraft is being tracked, sometimes 24 hours a day, by the Deep Space Network (DSN). The ACEs' primary functions are to monitor spacecraft activities to ensure proper execution of planned events, to operate the Ground Command System and radiate commands to the spacecraft, and to ensure the receipt of the highest possible percentage of science, engineering, and navigation data. The Data Technician assists the ACEs in distributing products and maintaining Mission Support Area equipment.

Most of the ACEs' time is spent monitoring the 2000 channels of telemetry radiated from the spacecraft to ensure that the spacecraft is operating as planned. The telemetry includes engineering data on the spacecraft as well as memory readouts from the science instruments. This task has been further complicated for Galileo with the loss of the high-gain antenna. Because the low-gain omni-antenna can provide a data rate of only 40 bits per second (bps), which drops to 10 bps as the cruise to Jupiter takes the spacecraft farther from Earth, it takes much longer to receive enough telemetry to verify the spacecraft's performance. At the 40 bps data rate, it takes 30 minutes to receive a full commutation of spacecraft telemetry. At 10 bps, two hours pass before the final bit of commutated data reaches the ground. If an anomaly occurs any time after a specific channel is received at the 10 bps rate, two hours pass before the alarm is confirmed.

The ACE is the first to learn of an alarm event. Alarms are identified when tolerances set by the analysts for each subsystem are exceeded. These alarms are displayed on a digital television alarm page and are routed to line

The Mission Control Team members are (seated from left) Susan Wieclawek, Jim McClure, Jr., Ralph Johansen, Jennifer Huynh, Allan Holland, and Belinda Arroyo, and (standing from left) John Louie, Ron Sharp, Jack Nash, Kathy Fimbres, Herlen Reed, Jr., Gene Brower, Dave Bray, Tom Fogle, and Steve Hillabrand.

printers. As the first priority, the ACE isolates the location of the problem. For problems in the Ground System, the ACE directs and coordinates corrective actions. If the problem is on the spacecraft, the ACE contacts the responsible subsystem analyst or manager and collects the data necessary to initiate restoration of the spacecraft to a normal configuration.

As a Command System operator, the ACE generates and packages preprogrammed command memory loads developed by the Sequence Team and transmits these files to the Deep Space Station computers, which in turn radiate the files to the spacecraft at the scheduled times. Real-time commands are usually determined by the Engineering and Science and Mission Design Offices' flight teams and pregenerated by the Sequence Team. However, predetermined classes of commands may also be generated by the ACE. These commands range in significance from routine monitoring and maintenance to an alarmed emergency response for a spacecraft in trouble.

As a coordinator, the ACE interfaces via voice nets with the DSN Track Controllers, who are in communication with the DSN complexes in Spain, Australia, and California, to ensure that the highest possible percentage of data is acquired and delivered to the Multimission Computer Control Center (MCCC) (now called Advanced Multimission Operations System, AMMOS). The ACE also interfaces with the AMMOS Operations Controller to establish the proper ground system configuration to process the data received from the DSN. In this role, the ACE becomes a system computer operator, directing the Space Flight Operations Facility project telemetry-system computers to control the way in which the data are manipulated. The data received electronically are packaged in blocks by the DSN stations and made available as hard-copy printouts and on video displays. To use these data, the ACE needs a working knowledge of the spacecraft and ground telemetry systems. In-depth analysis of the data, however, is handled by engineering specialists called subsystem analysts, who are members of the Orbiter Engineering Team.

To properly carry out their responsibilities, the ACEs need products provided by the real-time support function, the other half of the MCT. The real-time support function blazes an operations trail in establishing spacecraft tracking schedules, prioritizing and allocating Galileo's use of DSN antennas, providing spaceflight operations schedules, performing spacecraft command planning, conducting Project command conferences, and providing the sequence of events documents used by the ACEs to "fly" the spacecraft. This is the realm of the Ground Operations Engineer (GOE), Belinda Arroyo, who reports to Team Chief Jack Nash.

The GOE acts as the focal point internally between the real-time activities and real-time support functions and externally between the MCT and the other Galileo Project teams. The GOE coordinates the delivery of the real-time support function products, interfaces and assists with the timeline, command, sequence, and scheduling engineers, and presents the integrated MCT point of view to the Project when issues need resolution in a broader forum. The GOE leads the Project's effort to establish the weekly operations schedule, regularly coordinates with Division 37's Operation Engineering Laboratory on software changes and upgrades that affect the sequence generation, and monitors and supports the resource allocation negotiation process. In addition, the GOE maintains and assists in updating team operation procedures and interface agreements and is cognizant of Project mission and flight rule applicability for the team.

The weekly negotiations for the DSN long-range tracking antenna allocations can cover periods from 8 weeks to 5 years in the future. These long-range allocations are critical to the mission design because they provide the baseline footprint needed to assure that the required data are collected. If the

—see page 8

Leading the Mission Control Team

The MCT functions under the watchful eye of Team Chief John (Jack) C. Nash. Jack has a solid operations background, with 24 years at JPL in some form of operations support. His first 12 years on Lab were in Division 38, researching and developing solid propellants and polymer bindings. When the Lab transferred work on these materials to Edwards Air Force Base, Jack chose to work in operations. He joined the DSN as an Operations Chief, to handle both the MCCC and DSN operations. After 4 years, he became Network Operations Planning Engineer with Office 400, where he worked on the Viking, Voyager, Pioneer, Helios, Venus Balloon, and International Solar Polar Mission (Ulysses) Projects. From there he moved to Flight Projects' operations in Division 37, where he worked on the AMPTE, Voyager, and Galileo Projects.

"Most people on the outside of a project say they would find mission operations to be boring," says Jack, "but the reality is that the operations needed to capture new science, to recover a sequence, or reconfigure an anomalous spacecraft, when performed by the right mix of talented people, is exciting. Their skill assures the job will get done and done right. Project Galileo has such people in its MCT."

Up To Date

Operations Activity Summary

During this update time period (January 29–September 16, 1993), the spacecraft performed many operations, including attitude maintenance turn maneuvers (SITURNs), 10-N thruster flushes, two trajectory correction maneuvers, numerous power management activities, a radio-relay antenna (RRA) characterization test, several telecommunications tests, and a 10.5-rpm spin-up–down demonstration. Additionally, significant Command and Data Subsystem (CDS) flight software changes were loaded.

Attitude Control

Eight SITURNs were performed. Several of these SITURNs were in support of the high-gain antenna (HGA) X-band uplink and downlink tests. The spacecraft performance throughout these turn activities was normal.

The first post-Earth-2 flyby Trajectory Correction Maneuver, TCM-19, was performed on March 9 using the Z thrusters to impart a total delta velocity of 2.1 m/s. On August 13, TCM-20 was performed, consisting of one axial and one lateral segment imparting a total delta velocity of approximately 0.62 m/s. Preliminary radio navigation data indicated a 0.1 percent overburn in the axial segment. All Retropropulsion Module (RPM) pressures and temperatures and attitude control indicators were as expected.

Seven periodic RPM 10-N thruster maintenance flushing activities were completed. For these activities, all 12 thrusters were exercised, and spacecraft performance was normal.

The first 10.5-rpm spin-up–down activity was performed March 10–12 using a special mini-sequence. The spin activity used the new Attitude and Articulation Control Subsystem (AACS) phase 12.0 software, which was loaded on the spacecraft in late January. The entire spin activity was performed superbly with attitude control operation and RPM thruster counts near predicted values. The spacecraft achieved a spin rate of 10.49 rpm and remained at that rate for nearly 48 hours before spinning down and returning to dual-spin mode. The spin dynamic information collected was as expected, except for a higher-than-predicted wobble (~2 mrad). The cause for this is being investigated.

Calibration and Characterization Activities

Several AACS calibration activities were performed, covering the inertial and celestial sensors, spin-bearing assembly, and the scan platform actuator. The first inflight over-travel test was performed to verify that the platform could be safely slewed to cone angles between 153 and 209.6 deg. Performance and friction data were collected, and no unexpected events were observed.

In support of the Galileo mission with the low-gain antenna (LGA), two telemetry performance tests were conducted in late April and early May to characterize the link performance improvement with a suppressed carrier modulation technique using the DSN ARX advanced receiver. Data collected from both Deep Space Stations 14 and 15 at Goldstone, California, showed that performance improvement was near predicted theoretical levels.

The first RRA slew characterization test was performed during late April and early May. The RRA was incrementally slewed from its 4-deg off-stow position out to 53 deg and then incrementally back to about 6 deg off stow. Preliminary data analysis indicated that RRA control and monitor hardware are functioning properly and the antenna slew rate was within expected values.

HGA Activities

Two HGA X-band radio frequency (RF) tests were performed to determine if the asymmetric, partially deployed HGA has a usable RF gain lobe. An X-band uplink (7167-MHz) test, performed

Galileo Mission Summary*

Distance From the Earth	581,852,100 km (3.89 AU)
Distance From the Sun	460,733,100 km (3.08 AU)
Distance From Jupiter	380,705,300 km
Round-Trip Light Time	64 min, 46 s
Velocity Relative to the Sun	61,600 km/h
Spacecraft–Sun Angle	8 deg off Sun
Spacecraft Spin Rate	2.89 rpm
Spin Configuration	All spin
Downlink Telemetry Rate	40 bits/s (coded), LGA 1
Powered Science Instruments	Dust Detector Subsystem, Energetic Particles Detector, Extreme Ultraviolet Spectrometer, Heavy Ion Counter, Magnetometer, Plasma Wave, and Ultraviolet Spectrometer
General Thermal Control	All temperatures within acceptable ranges
RTG Power Output	512.6 W
Real-Time Commands Sent	72,410 commands

*As of September 16, 1993.

in mid-March, was similar to the test performed in May 1991. RF data analysis indicated the possible presence of a gain lobe, about 4 to 6 dB better than that of the LGA, located about 1 deg off boresight.

In mid-June, the first HGA downlink test was performed. The test was conducted using the X-band (8420-MHz) transmitter flight equipment. This test was the first operation of the X-band transmitter in nearly 4 years. All X-band hardware engineering telemetry data were within predicted levels. The downlink test was conducted with the X-band transmitter in the low-power mode simultaneously with the S-band in the high-power mode, radiating via the LGA. The HGA signal was coarsely mapped to about ±20 deg off boresight, and finely mapped every 0.25 deg within 4 deg of boresight. Preliminary analysis indicates no useful gain lobe exists.

Sun-Shade Retraction

On March 4, the Energetic Particle Detector's (EPD's) pyro-activated protective sun shade was retracted using the spun pyro-switching unit. All CDS and pyro telemetry data indicated proper activation. Within hours, as predicted, EPD detector temperatures increased, confirming sun-shade retraction. This was the final, planned pyro event prior to Probe release activities in July 1995.

Anomaly Status

AC/DC Imbalance

The ac/dc bus imbalance measurements continue to fluctuate. The ac imbalance measurement exhibited changes of a few data numbers (DNs), varying from about 3.6 to 4.8 V. The dc measurement, however, changed abruptly within a 24-hour period, from about 16 to 4 V, and then returned to nearly 16 V. The large fluctuations occurred during spacecraft quiescent periods in dual-spin cruise mode. Subsequently, the dc imbalance measurement stabilized and then gradually increased to its present level of about 18.8 V.

Spacecraft Safing

The spacecraft entered safing five times during this update period because of CDS transient power on reset (POR) events. After 692 days without a transient CDS bus reset POR, CDS "A" bus reset events recurred on June 10 and 17, July 10 and 11, and August 11. Recovery from the bus reset PORs was accomplished expeditiously using off-the-shelf contingency command files developed, approved, and tested months before. The CDS returned to the fully redundant mode in about 30 hours for June events and in about 12 hours for the July 11 event. During the recovery process from the July 10 bus reset, another bus reset occurred on July 11. The cause of these POR anomalies is believed to be slip-ring brush-wear debris, which builds up and forms conductive paths among spin-bearing assembly electrical interfaces. The unwanted circuit paths, in conjunction with simultaneous brush lifts, produce a transient POR signal, which is detected by the despun CDS electronics.

Scan Platform Slew

During the AACS phase 12.0 memory load and verification activity—just after the "A" memory swap event with the 12.0 software loaded—the scan platform unexpectedly slewed at the high rate and hit the mechanical stop before returning to the 153-deg cone-angle safe position. The cause of the anomaly was a software timing flaw that existed before launch. An AACS software patch was sent to the spacecraft to preclude this anomaly in case of a future memory swap. A tiger team analysis effort was formed to assess the integrity of all the scan-platform-mounted hardware, including science instruments, gyros, accelerometers, and structural elements. Slew-induced, analytical loads were compared with prelaunch test-loads, and gyro and accelerometer flight tests were performed. Worst-case analyzed loads showed significant margins for all equipment. Gyro and accelerometer flight test data showed no perceptible change from earlier baseline data, strongly suggesting no hardware damage or misalignments.

Ground Data Systems

Galileo participated in the DSN Ground Communications Facility 1.5 upgrade data-flow tests in February and March. These tests demonstrated a new Galileo telemetry data-flow path through the DSN Space Flight Operations Center gateway to the Multimission Command Mission Control and Computing Center (MCCC) and Multimission Ground Data System (MGDS).

The IBM 3090/200 to ES/9000 transition certification testing activities began on February 22. No significant problems occurred and no errors were reported. Galileo made the transition from the IBM 3090/200 to the new IBM ES/9000-6121/610 on April 3.

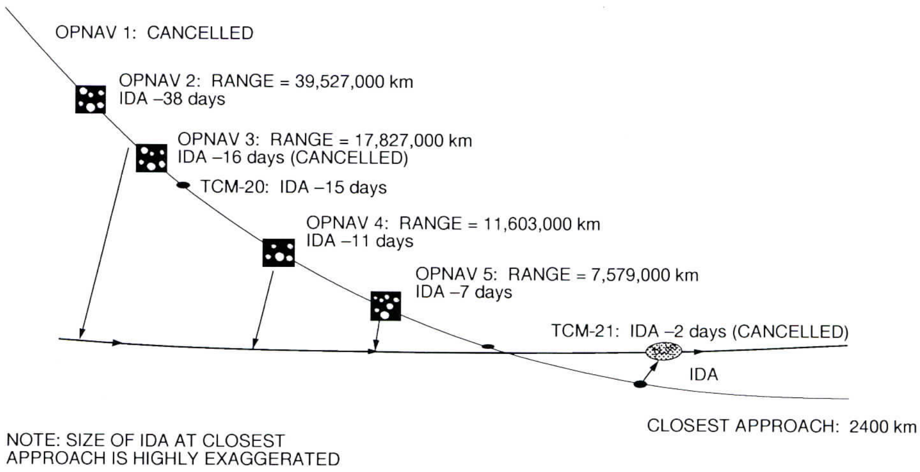
In March, Multimission Operation System Office (MOSO) system tests for Galileo MGDS tested the integrity of the version 18 command system with the DSN. In May, Galileo participated in additional MOSO system tests using DSSs 43 and 42. The tests demonstrated Galileo MGDS compatibility with the MOSO database's ability to transmit to the Command Processor Assembly and radiate command files. Successful MGDS tests for version 18.1 were conducted in June and July. Galileo has started parallel operations with version 18.1 command system and plans to decommit MCCC in October.

A Galileo mission verification test was performed on June 8 using DSS 15 to evaluate the ability of the new type-A telemetry group controller (TGC) and telemetry channel assemblies (TCA) to support

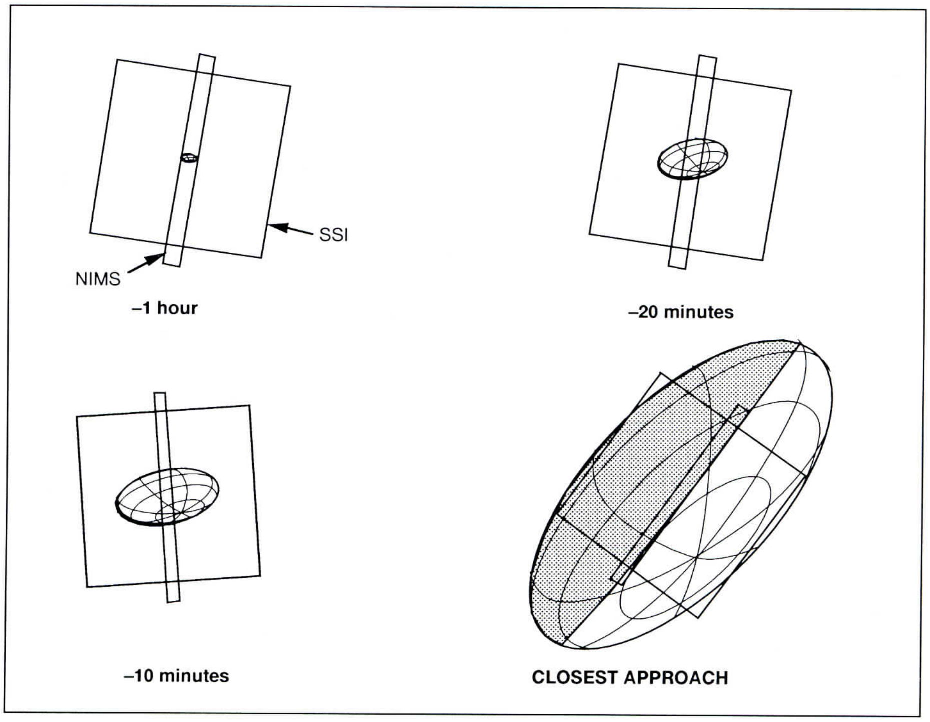
Galileo. This test demonstrated the telemetry and monitor functions for Galileo on both MCCC and version 18.1 MGDS. The type-A TGC/TCA went into soak operations on June 18.

Sequence Generation

Several special mini-sequences were developed in support of spacecraft operations. The TCM-19 sequence memory load was generated and approved for transmission on March 5. The HGA uplink and downlink RF test mini-sequences were generated and approved for transmission on March 13 and June 17, respectively. In late April, the RRA slew test mini-sequence was generated and approved for transmission. In addition to these efforts, the nominally planned Earth–Jupiter (EJ) sequences, EJ-1, EJ-2, and EJ-3A and -3B (Ida encounter), were completed. As a consequence of the bus reset PORs, the EJ-2 Ida approach sequence was regenerated as EJ-2' and EJ-2". Also, several reserve box sequences were developed for the return of Ida data. Cruise plans are also underway for the EJ-4, EJ-5, and EJ-6 sequences, which cover the period through the end of August 1994.



A single optical navigation (OpNav) image and TCM adequately pointed Galileo's camera at asteroid Ida.



The NIMS and SSI instruments made a variety of observations as the spacecraft neared Ida.

Software

Several CDS flight software changes were made in mid-June to incorporate various fault protection updates, the IM-4 anomaly fix, and addition of the new 80-byte memory readout capability, which replaced the 32-byte capability and permits faster return of spacecraft stored data. This new capability was used to return the Ida images.

An AACS 12.0 flight software patch was loaded to preclude recurrence of the scan platform slew anomaly in the event of an AACS memory swap.

Twenty-seven failure reports (FRs) were included in the MIPS version 9.0 deliveries, which provided corrections to support Plasma Wave Subsystem and Near Infrared Mapping Spectrometer processing. A POINTER waiver delivery was made to support solid-state-imaging exposure calculations at Ida.

The E1.0 software set of 19 program sets was delivered as part of the April 1 E1.0 Mission Build. The E1.1, containing three program sets correcting 16 FRs and implementing 7 software change requests (SCRs), was delivered as part of the May 15 E1.1 Mission Build. The E1.2, containing three program sets correcting 65 FRs and implementing 4 SCRs, was delivered on June 11.

The E2.0 software delivery activities will continue through November.

— *Matt Landano*
Deputy Mission Director

MCT from page 4

proper resources are not allocated to Galileo on critical dates, unique scientific and engineering data could be lost. Other projects and users vie for the same resources during these weekly long-range allocation meetings so they, too, can take full advantage of their spacecraft's capabilities. This leads to specific track coverage challenges that have to be resolved before the projects can proceed with their mission designs. Most of the time, satisfactory compromises can be reached; however, relatively small variances of 15 to 30 minutes in the start- and end-of-track allocations can be carried forward to the week before a sequence starts. These minor conflicts are resolved at weekly meetings of a group concerned with real-time changes—the period from the current day to 8 weeks in advance. This scheduling function dovetails with the long-range scheduling function and provides for last-minute changes in equipment and track times.

Once the schedules and resource allocations are set, the MCT real-time support function supplies products to many customers, including the Sequence, Engineering, and Design Teams. These products allow each of the Project's teams to determine when their tasks need to be completed.

A large part of the Mission Control Team's real-time support products are generated by the Timeline Engineer (TE), Jennifer Huynh. The TE provides the final profile for station allocations of DSN antenna time for Galileo. In addition, the TE prepares the spaceflight operations schedule (SFOS), which is a day-by-day agenda for Project and team meetings and spacecraft commanding and tracking; the ground events profile, which projects events for the coming month; and the integrated mission operations profile, which covers the Project through the end of its prime mission.

Actual operation of the Galileo spacecraft can result only through the combined integration of ground and spacecraft events, which are presented as a sequence of events (SOE), prepared by the SOE Engineer. The SOE Engineer receives the spacecraft events file from the Sequence Team, and the resource allocations from the MCT scheduling engineers. From the resource allocations, the ground events file is generated. The SOE Engineer then integrates the spacecraft and ground events files to produce the SOE used by the Flight Team to "fly" the spacecraft. This product is the official flight operations document for Project Galileo.

A real-time support interface between the command planning process and the ACE is the Command Engineer (CE), Jim McClure, Jr. The CE's primary responsibilities are reviewing, constraint checking, scheduling, and presenting real-time command requests to the Galileo Mission Director for approval. Upon approval, these command requests must be prepared for transmittal to the Galileo spacecraft. The CE works with the ACE to ensure that, from each command request, the proper commands are generated and safely transmitted through the DSN to the spacecraft. The CE also provides real-time command information to the Timeline Engineer and the SOE Engineer for inclusion into the SFOS and SOE.

As custodian of the Galileo contingency command library, the CE also plays a significant role in responding to spacecraft anomalies and emergencies. Real-time commanding of the spacecraft has increased because of the high-gain antenna anomaly—over 60,000 real-time commands have been radiated thus-far in unsuccessful attempts to free the antenna. Since dedication and attention to detail are required for safe and prompt commanding of the spacecraft, the CE must be knowledgeable about the ground data system and the spacecraft, and always strive for perfection.

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The Galileo Messenger

Issue 33 February 1994

From the Project Manager

Galileo's progress continues to be excellent on all fronts. A most noteworthy recent achievement is the reengineering of the uplink process—the process by which desired science observations, engineering, and navigation activities are designed, checked, and translated into command files that are sent to the spacecraft. Immediately after the Ida encounter, we chartered an Uplink Reengineering Team led by Mission Director Neal Ausman with a goal of reducing the cost of the uplink process as much as possible without substantial science loss. The team widely solicited ideas and many people contributed. The results are very impressive and have been enthusiastically endorsed by JPL and NASA. We are reorganizing the Flight Team to reduce and streamline interfaces, rescheduling uplink products, and implementing new tools and techniques. The transition will be completed by July. We estimate a cost savings of nearly 50 percent of the previous budget for the uplink process from now to the end of mission.

The development of the new capabilities to perform the Jupiter mission with the Low-Gain Antenna (LGA) is right on schedule and, in many respects, these capabilities are better than originally envisioned. The Phase 1 CDS software [Relay/Jupiter Orbit Insertion (JOI)] was delivered to system test on February 1. The Phase 2 design (Orbital Tour) passed its Critical Design Review (CDR) with flying colors last month. The overall Final Mission and System Review (FMSR) was equally successful last November. The momentum is exhilarating!

On the spacecraft front, we got quite a surprise on September 24th when a CDS transient bus reset occurred in all-spin for the first time. We had thought the resets were related to brush bounce on the Spin Bearing Assembly slip rings. Now we are searching for other explanations. Fortunately, due to numerous resets last summer, we already have augmented the Phase 2 flight software design with the capability to autonomously detect the reset, recover the downstring, and continue the spacecraft sequence—so these resets will not be a problem for Jupiter orbital operations. The Relay/JOI sequence is not threatened because that critical sequence has always been designed to continue

—see page 8

Steering a Course to Jupiter: Meet the Galileo Navigation Team

For almost a decade, a relatively small group of people have focused on calculating the best trajectory for the Galileo spacecraft on its 3.8-billion-kilometer flight to Jupiter and subsequent satellite tour. The Galileo Navigation Team, led by Bill Kirhofer and Lou D'Amario, is tasked with designing and controlling the flight path that achieves all mission science goals within a very tight propellant budget and mission operations constraints. It's an assignment that has been exciting, challenging, and occasionally frustrating.

After a second pass through the asteroid belt and a spectacular flyby of the asteroid Ida, Galileo is now on a direct course for Jupiter. The team's general task now is to determine the spacecraft's optimal flight path by comparing real-time tracking (or radio-metric) data to the nominal profile. "It's a constant reoptimization process," says Bill Kirhofer. "Our goal is to use the minimum amount of propellant while satisfying all the constraints en route to Jupiter."

Team Structure

The Galileo Navigation Team is made up of three major groups: Orbit Determination, Trajectory Analysis, and Maneuver Analysis. The Orbit-Determination Group, headed by Frank Nicholson, solves for the best estimate of the actual current trajectory and predicts the

The Galileo Navigation Team: (front row, from left) Mike Wang, Peter Antreasian, John Neff, Jennie Johannesen, Joan Pojman, Aron Wolf, Ed Rinderle, and Chris Potts; (back row, from left) Bill Kirhofer, Bob Gaskell, George Null, Dan Cziczo, Ed Riedel, Dennis Byrnes, Frank Nicholson, Lou D'Amario, Bob Mase, Pieter Kallemeyn, Duane Roth, Mike Wilson, Greg Garner, and Allen Halsell. (Not pictured: Peter Breckheimer, Gene Bollman, Nick Christenson, Robert Davis, John Ekelund, Robert Haw, and Steve Synnott.)

orbit-determination capabilities available for future phases of the mission. An important subfunction of this group is optical navigation (OPNAV) analysis. OPNAV images are used in combination with radio-metric data for precision delivery of the spacecraft to its targets, such as asteroids and satellites. Analysts involved in the Orbit Determination Group are: Peter Antreasian, Robert Davis, Bob Gaskell, Robert Haw, Pieter Kallemeyn, Robert Mase, George Null, Duane Roth, Ed Riedel, and Steve Synnott.

The Trajectory Analysis Group, headed by Jennie Johannesen, calculates the optimal deterministic trajectory that minimizes propellant consumption, while satisfying mission and science requirements. This group also determines the proper trajectory for delivery of the probe into Jupiter's atmosphere, performs probe-orbiter relay-link analyses, and produces numerous trajectory data files and other products for science planning, sequence development, and analysis. Members of the Trajectory Analysis Group are: Dennis Byrnes, Greg Garner, Jon Neff, Joan Pojman, Ed Rinderle, and Aron Wolf.

The Maneuver Analysis Group, headed by Michael Wilson, determines the velocity changes (ΔV) required at each trajectory-correction maneuver to maintain the spacecraft's optimal trajectory and develops the best maneuver strategy to compensate for statistical trajectory dispersions. In addition, it estimates future statistical ΔV and propellant requirements. Members of the Maneuver Analysis Group are: Gene Bollman, Dan Cziczo, Allen Halsell, and Chris Potts.

The Software Group, led by P.J. Breckheimer with John Ekelund, Navigation System Software System Engineer, offers more of a multimission contribution. Mike Wang is responsible for maneuver analysis software maintenance and Nick Christenson oversees the Navigation Team's computer hardware and networks. Jennie Johannesen also serves as the Software System Engineer for the Mission Design System software set.

Altogether, the people in these four groups represent about 19 full-time persons in terms of total workforce spent on Galileo's navigation.

Important Accomplishments

The Galileo Navigation Team has achieved several accomplishments since the Project began. Most notable were innovative changes to the spacecraft trajectory in response to the 1986

Challenger accident. Galileo was to have launched the same year that the Challenger accident occurred. As a direct result of the accident, NASA decided not to use the high-energy liquid-propellant Centaur upper stage in the Space Shuttle for safety reasons. The two-stage solid-propellant Inertial Upper Stage (IUS), with a much lower injection energy capability, was substituted instead.

For the Navigation Team, this meant the design of a new baseline trajectory to Jupiter using about one-fifth of the injection energy originally planned. Necessity being the mother of invention, the concept of the VEEGA (Venus–Earth–Earth Gravity Assist) trajectory was developed. The VEEGA trajectory uses the gravitational pull from Venus and Earth (twice) to help propel the spacecraft to Jupiter. A permutation of the propellant-saving concept is now being incorporated by the Cassini Project and is being considered for other outer-planet missions.

Once the VEEGA trajectory had been baselined by the Project, a significant challenge was finding a way to add one or more asteroid flybys to the interplanetary trajectory for little or no propellant cost. This involved a rigorous search for asteroid-flyby candidates and an evaluation of the propellant cost for each. The result allowed Galileo flybys of the asteroids Gaspra and Ida for a relatively modest propellant cost.

The Navigation Team also faced major obstacles in navigating the spacecraft from launch through completion of the VEEGA trajectory. In particular, a complex maneuver aimpoint biasing strategy was developed and carried out to minimize the risk of Galileo reentering the Earth's atmosphere at the two flybys. Also, optical navigation was successfully used for the first time to aid Galileo's orbit determination at the Gaspra and Ida asteroid flybys. Finally, because of the greatly reduced number of OPNAV images due to the unavailability of the high-gain antenna, a novel single-frame-mosaicking technique was used to obtain multiple data points from a single OPNAV image.

Since the team achieved very accurate delivery of the spacecraft to the desired aimpoints at the Venus and Earth gravity-assist flybys, a significant amount of propellant was saved and several planned trajectory-correction maneuvers were eliminated. This, in turn, allowed the mission to proceed with the second asteroid flyby. Accurate navigation delivery also eliminated the need for science pointing updates at the two asteroid flybys, which reduced both risk to the asteroid-science sequence and the amount of ground effort required for uplink development.

Future Challenges

Galileo's planetary-gravity assists and asteroid flybys have now been completed, and the spacecraft is on a direct trajectory to Jupiter with arrival to occur on December 7, 1995. It is currently about 300 million kilometers from Jupiter; the last asteroid flyby occurred in August 1993. Many navigation hurdles lie ahead in the Jupiter approach and encounter. At approximately 150 days from Jupiter, the spacecraft will release a probe targeted to enter the Jovian atmosphere. Seven days later, the orbiter will perform a

—see page 5

More About the Team Chiefs

Bill Kirhofer, Navigation Team Chief, graduated from the Northrop Aeronautical Institute (1954), received his B.S. in mechanical engineering from UCLA (1958), and earned an M.S. in aeronautical engineering from Caltech (1961). After graduation in 1954, he began his career working at the Caltech· ·Southern California Cooperative Wind Tunnel. He transferred to JPL in 1960 and has worked on the Ranger, Surveyor, Mariner, and Pioneer Projects, as well as on Galileo. Beginning as a trajectory analyst for Rangers III and IV, he became a Navigation Team Chief on Ranger VII. He served as the Space Flight Operations Director for Mariner V and as the Navigation Team Chief for Pioneer 10 and 11 (Jupiter/Saturn) and Pioneer 12/13 (Venus Orbiter/Multiprobe). He was assigned to the position of Galileo Navigation Team Chief in 1980.

Lou D'Amario is a graduate of Rensselaer Polytechnic Institute in Troy, New York, with a B.S. in aeronautical engineering (1968). He attended graduate school at the Massachusetts Institute of Technology, where he completed his M.S. (1970) and Ph.D. (1973) in aeronautics and astronautics. Lou worked at the Charles Stark Draper Laboratory at MIT for 4 years, where he was involved in Space Shuttle flight-control systems. He came to the Laboratory in 1977 and his entire JPL career has been spent on the Galileo Project. Initially, he was a trajectory analyst; then he became the trajectory group leader and then Mission Design Manager (from 1988 through launch); he has been the Deputy Navigation Team Chief since 1988.

Revisiting the Asteroids: This Time It's Ida

Galileo's second encounter with an asteroid was a great success and has added much to our understanding of these bodies in our solar system. On August 28, 1993, Galileo swept within 2400 kilometers of Ida, at a relative velocity of 12.4 kilometers/second, capturing many images of the asteroid.

Ida is 56 kilometers long, and is heavily cratered. This extensive cratering seems to contradict earlier theories that Ida is a relatively young asteroid, although views of other portions of the asteroid (to be returned this spring) may shed more light on this.

Previously, many scientists did not believe that asteroids had magnetic fields, because they are too small to have a dense metallic core. However, if the current asteroids are pieces of larger "parent bodies" that were broken apart, they could have magnetic fields. Another possibility is that strong fields in the solar wind were imposed on the asteroids at a time early in the solar system when they were heated more than now.

Dr. Margaret Kivelson, Principal Investigator for the Magnetometer and a physicist at UCLA, heads up the Galileo investigation into magnetic fields. As at asteroid Gaspra in October 1991, Galileo again detected changes in the interplanetary magnetic field as it passed Ida. Both times the instrument measured several swings or shifts in the direction of the magnetic field, called field rotations, which Dr. Kivelson believes may be produced by the asteroid's interaction with the solar wind. If so, the observations do not necessarily show that Ida has a magnetic field. However, coupled with the same findings at

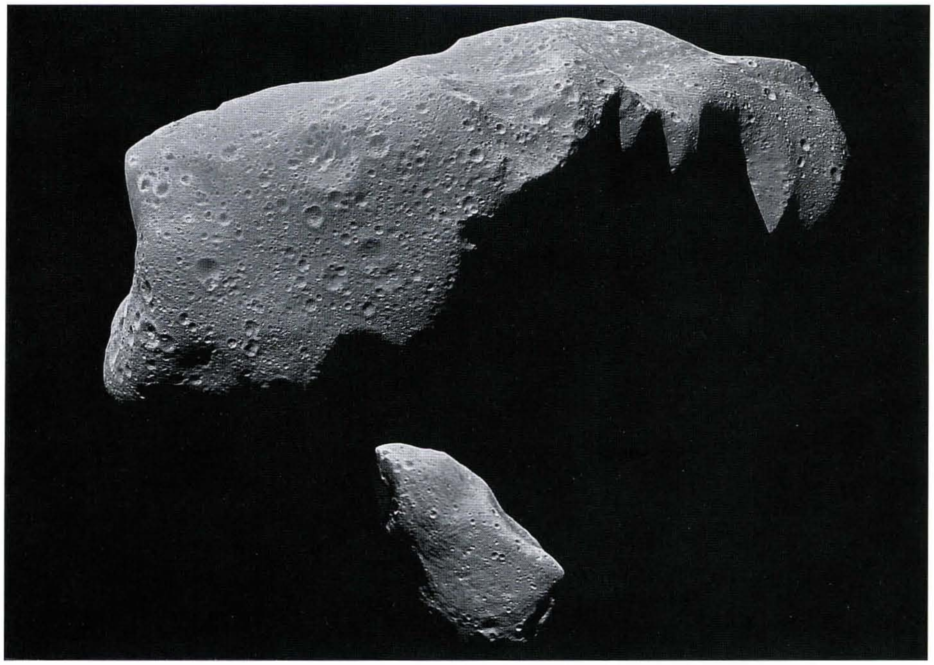

Fig. 1. A dramatic size comparison of the asteroids Ida (top) and Gaspra. Ida is 56 × 24 × 21 km but Gaspra only measures 19 × 12 × 11 km. (P43071)

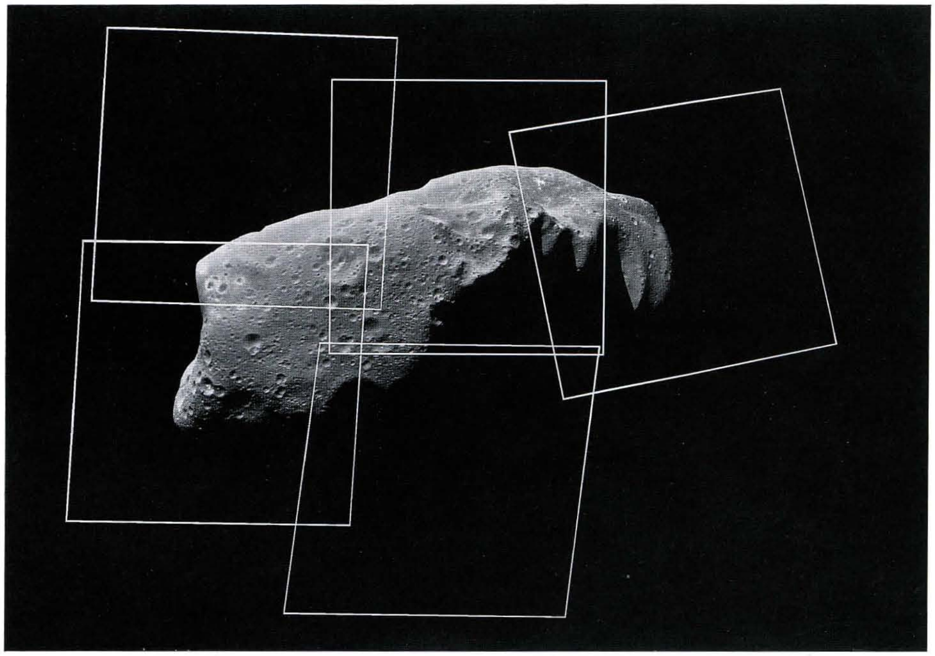

Fig. 2. A mosaicking technique was used to capture Ida images. As shown, five images of the asteroid were pieced together to create this completed photograph. (P43072)

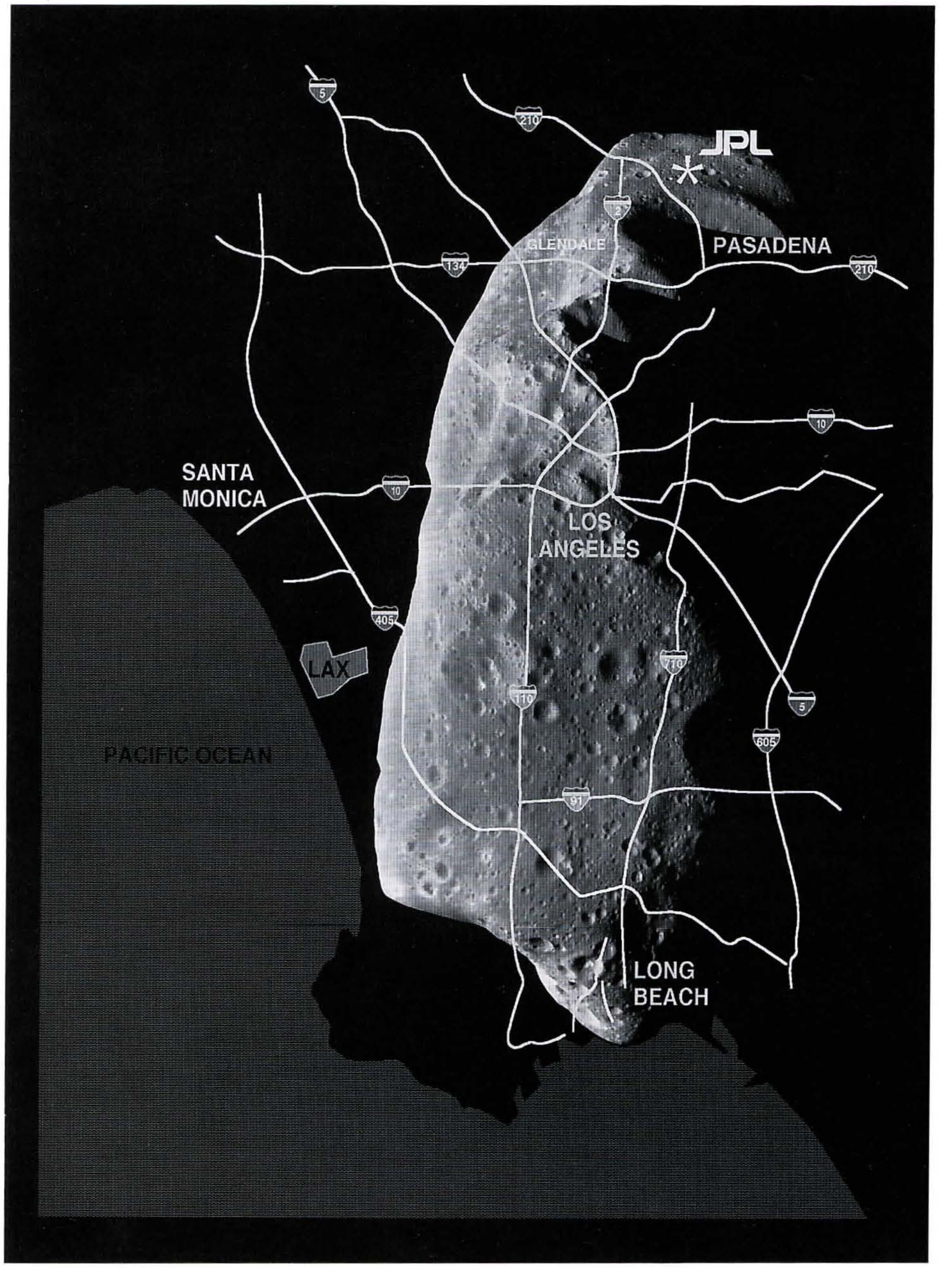

Fig. 3. How big is Ida? This image gives us a more tangible idea of the asteroid's size by superimposing it on a map of the Greater Los Angeles freeway system. Its 56-km (35-mile) length is equivalent to driving from the Jet Propulsion Laboratory (JPL) in Pasadena to Long Beach. The smaller visible craters are about the size of the Rose Bowl. (P43077)

asteroid Gaspra, indications are strong that such magnetic fields exist.

Galileo may have a unique opportunity to view a comet impacting a planet. In July 1994, Comet Shoemaker–Levy is expected to collide with Jupiter, and Galileo should be able to view the impact. Detailed planning for these observations will begin in March.

NAVIGATION TEAM from page 3

deflection maneuver to target the trajectory for the Io flyby, probe relay, and Jupiter orbit insertion.

After orbit insertion, Galileo will conduct an 11-orbit, 23-month satellite tour, which will include 10 close flybys of the three outermost Galilean satellites: Europa, Ganymede, and Callisto. During 1992, the team designed about a dozen candidate satellite tours with the objective of satisfying all tour science requirements within propellant and mission constraints. This effort was built upon past experience in designing satellite tours for other mission baselines. There was intense interaction between the tour designers and the science teams to determine proper tradeoffs between science content and propellant requirements.

The three science working groups unanimously recommended the 92-14A satellite tour, and it was selected by the Project Science Group on April 30, 1992. Because this tour had especially low propellant requirements, it was another important factor in the decision to proceed with the second asteroid flyby.

Lou D'Amario summed up by saying, "The satellite tour design effort involved key contributions by all three groups of the Navigation Team. We felt that 92-14A was the best satellite tour developed for the VEEGA mission, and its selection was extremely satisfying for the team."

Optical navigation will be an essential element in achieving precision deliveries at the Jovian satellites. One recent achievement is the development of algorithms that edit the optical navigation data for a single image down to a manageable amount: now the data can be returned to Earth in approximately 2 hours, as compared to 12 days without this editing.

Up To Date

During this update period (September 16-December 31, 1993), the spacecraft performed operations activities associated with health and attitude maintenance, telecommunications link characterization, trajectory-correction maneuvers, routine cruise science memory readouts, and early return of Ida data.

Attitude Control

Three spacecraft turns (SITURNs) were performed during this period: a 5.2-degree turn on October 1 to position the spacecraft attitude for Trajectory Correction Maneuver (TCM)-22, a 19.1-degree turn on October 22, and a 14.3-degree turn on December 2 for routine attitude maintenance.

TCM-22 was performed in five portions from October 4 through 8. It was the largest maneuver to be performed using the 10-N thrusters. The TCM used the lateral (L) thrusters to impart a delta velocity of nearly 39 meters/second. Each L thruster accumulated more than 4800 burn pulses. All attitude control indicators and Retropropulsion Module (RPM) pressures and temperatures were as expected. Radio navigation data indicates a near-perfect maneuver execution with less than 0.2-percent underburn.

Four routine periodic RPM 10-N thruster maintenance flushing activities were completed. All 12 thrusters were exercised and performance was normal.

Special Telecommunications Test

To support the mission with the low-gain antenna, the first of a series of tests was performed to characterize the link performance during solar conjunction. The tests used Deep-Space Stations (DSS) 14 and 12 to observe solar effects on the S-band link performance. DSS 14 monitored the signal with the normal Block IV receiver, while DSS 12 used the engineering model Block V receiver (ARX). Because of the weak signal at DSS 12, the ARX was unable to achieve lock on the suppressed carrier spacecraft signal. For the portion of the tests where the downlink carrier was present, the observed link effects were near expectations. The tests demonstrated that telemetry data lock at DSS 14 was intermittent inside about 4 degrees of the Sun. Command link performance, using the DSN 100-kW transmitter was also intermittent inside 4 degrees based on command detector unit (CDU) lock change count telemetry.

Additional tests will be performed in February/March 1994 using DSS 14 and, again, during the solar conjunction period in late 1994 using the Block V receiver at the 70-meter station at Canberra (DSS 43).

Anomaly Status

AC/DC Bus Imbalance. The AC/DC bus imbalance measurements continue to fluctuate. The AC measurement exhibited changes of a few data numbers (DNs) and remains fairly stable near 4.8 volts. The DC measurement changed only slightly, varying between 17.5 and 18.8 volts.

Spacecraft Safing. The spacecraft entered safing due to a CDS-A transient bus reset on September 24. This event was the first transient reset observed in all-spin mode. The previous eight events occurred with relative motion between the spun and despun sections. Because the all-spin event was totally unexpected, the special anomaly tiger team was reconvened to reexamine the problem and search for possible causes (acting alone or in concert with brush debris) and to reassess the operating spin-mode recommendation.

On December 2, a special anomaly review board was convened to assess the new investigative efforts. The board agreed that producing additional brush debris is clearly undesirable and unanimously endorsed the recommendation to operate in quasi all-spin mode unless mission events require all-spin/dual-spin. Further work to understand the all-spin bus reset anomaly is being pursued.

AACS Anomaly. About 4 hours before Ida closest approach, the spacecraft autonomously turned off its gyros and switched to cruise mode. About 3 hours after this event, another anomaly occurred resulting in several SAS and SBA violation counts and an approximate 20-W increase in AC power load. As observed from the Ida photo returned, these anomalies had no effect on the quality of the high-resolution image.

Efforts to recreate the anomaly on the testbed and other AACS simulators have been unsuccessful. Further investigative actions being considered are DMS playback of selected spacecraft engineering data and an in-flight test to try to recreate the anomaly.

PLS Low-Temperature Alarm. About 9 hours from Ida closest approach, the Plasma Subsystem (PLS) instrument fell below flight-allowable (3-210) limits. No real-time action was taken because the sequence-stored command to turn on the high-voltage electronics raised the heat dissipation enough to stabilize about 4 degrees above cold qualification limits. The Principal Investigator determined that there is minor concern for the safety of the instrument, but requested early return of some low-rate science data to verify its health.

EUV Anomaly. As part of the recovery from the September 24 CDS bus reset anomaly, the EUV instrument was powered again on

October 11 and completely reconfigured on October 13. Instrument routine memory readout (MRO) on October 14 revealed some corrupted data indicating an instrument anomaly. After diagnostic MROs and interaction with the Principal Investigator (PI), the EUV was turned off on October 15. Internal troubleshooting activities were performed by the PI organization to determine the cause of the problem. Despite the effort, the cause could not be found. It was thought, however, that the corrupted data may have been the result of the instrument MRO associated with turn on. Consequently, the PI requested that the EUV turn-on library sequence be modified to delete the MRO. The request was accepted and the instrument was powered on November 19 and has since operated without anomaly.

Early Return of Ida Data

Return of the entire high-resolution Ida encounter image was completed on September 22 using the last day of 40-bits-per-second (bps) telemetry capability until early in 1994. A total of 35 Data Memory Subsystem (DMS) MROs was used to return the five imaging frames containing Ida. Spacecraft performance throughout early data return was normal. The remainder of Ida data is scheduled to be retrieved between early March and late June of 1994 when 40-bps telemetry performance is again available.

Sequence Generation

Five Reserved Box Sequences were developed for the playback of Ida data. Other sequences generated were the EJ-4 and preliminary EJ-5 products. The EJ-4 sequence covers the spacecraft activities from September 27, 1993, to January 14, 1994.

Ground Data System (GDS)

The GDS test program has successfully verified command capabilities within the Galileo testbed environment with the completion of GDS testing of the MGDS Version 18.1.1 Command. A review of this testing was conducted September 30.

A Multimission Operations Systems Office (MOSO) combined test team and Galileo pre-GDS test of MGDS Version 19.0 was conducted October 7 and 8 on the Galileo testbed with the MGDS Test Telemetry and Command System. The test successfully demonstrated the system's processing ability. Telemetry engineering rates of 1200-, 40-, 16-, 10-, and 8-bps were exercised during the test. The MOSO Functional Area Test Review (FATR) was conducted December 1 to assess Version 19.0's readiness to begin MOSO system testing, Project user acceptance testing (UATs), and GDS testing.

Galileo made the command system transition from Mission Control and Computer Center (MCCC) to Advanced Multimission Operations System (AMMOS) on November 1.

E2.0 software-delivery activities have been completed and the Data Management System (DMS) successfully completed its acceptance test and delivery reviews on December 10. The DMS deliveries implemented seven planned Software Change Requests (SCRs) and 11 planned Failure Reports (FRs). The DMS deliveries went on-line for operational support on December 15. Mission builds for the E2.0 included 28 program sets, or approximately two million lines of code, and incorporated 37 SCRs and 187 FRs.

—Matt Landano

Galileo Mission Summary*

Distance from Earth	656,217,600 kilometers (4.39 AU)
Distance from Sun	557,045,500 kilometers (3.73 AU)
Heliocentric Speed	50,200 kilometers per hour
Distance from Jupiter	321,716,500 kilometers
Round-Trip Light Time	72 minutes, 56 seconds
System Power Margin	44 W
Spin Configuration	All spin
Spin Rate/Sensor	2.89 rpm/Star Scanner
Spacecraft Attitude	Approximately 9 deg off-Sun (leading) and 1.5 deg off-Earth (leading)
Downlink Telemetry Rate	10 bps (coded) Low-Gain Antenna-1
General Thermal Control	All temperatures within acceptable ranges
RPM Tank Pressures	All within acceptable ranges
Powered Science Instruments	Plasma Wave Spectrometer, Extreme Ultraviolet Spectrometer, Ultraviolet Spectrometer, Energetic Particle Detector, Magnetometer, Heavy Ion Counter, and Dust Detector Subsystem
Real-Time Commands Sent	73,136 commands

* All information is current as of December 31, 1993.

PROJECT MANAGER from page 1

to completion in the presence of numerous faults, including one side of the CDS going down.

The first week of October, the spacecraft was commanded to execute the largest maneuver that will ever be required of its 10-N thrusters—TCM22. Each day, Monday through Friday, a 9-hour maneuver portion was performed. A grand total of nearly 5,000 pulses on each of the two lateral thrusters imparted 38.6 m/sec to target the Galileo Probe to the center of its entry corridor. (The Probe remains attached to the Orbiter until its release on July 13, 1995.) This marked the first time Galileo was targeted to Jupiter–Ida was our last intermediate target. Our most recent orbit determination shows TCM22 to be the most accurate maneuver yet—only a 0.15-percent underburn. A 0.1-m/sec TCM22A will be executed February 15th to correct this residual error.

We are all very saddened that the Mars Observer spacecraft could not be recovered. It is a reminder to us all that these missions are very difficult and can be most unforgiving. Matt Landano, our Deputy Mission Director and formerly the Galileo Spacecraft System Engineer during development, is leading a team of specialists in a thorough review of all the findings of the several Mars Observer (MO) investigation boards. We are committed to making sure that any lessons from this incident are appropriately incorporated into our operation of the Galileo spacecraft. We have already determined that the Galileo design does not allow any of the most likely single-point failures identified by the MO investigations. And, very importantly, the Galileo propulsion system was fully pressurized near the end of the launch sequence and has operated flawlessly in over four years of flight now.

This month, we are "jailbar"-searching the DMS tape to precisely locate the rest of the Ida data. Over the next four months, we will return most of this data to Earth at 40 bps using the DMSMRO technique.

Yet another coup awaits Galileo this summer. Comet Shoemaker–Levy 9, now a string of 22 fragments, will impact Jupiter in late July producing the most cataclysmic solar system event in centuries. The impacts will occur on the farside of Jupiter as seen from Earth. Although Galileo will still be 16 months from Jupiter arrival, it will essentially already be on its approach asymptote, affording a viewpoint 40 deg different than Earth's. The impacts will be well on the visible disc of Jupiter as seen by Galileo and in the predawn region. Each impact should produce a tremendous brightening. Earth observers, including the Hubble Space Telescope, will have to wait several hours for Jupiter's rotation to bring each impacted area into view, so they will see only the aftermaths—Galileo alone will view the events first hand. We are advancing an Orbital Phase capability to greatly improve our coverage of these events. New software will be sent to Galileo's camera (SSI) to allow us to shutter many exposures onto the CCD chip before reading out the image. Jupiter will be about 60 pixels in diameter on the 800-by-800 chip so we can comfortably capture, for example, a 7-by-7 array of 49 Jupiter images on a single frame by moving the scan platform between each exposure. Depending on how much tracking time we can get over the rest of the year (Ulysses is now our greatest competitor for DSN time), we hope to return the data equivalent of between 5 and 10 frames. To account for the uncertainty of the impact times, we will fill the tape recorder with imaging frames and other science data and then playback only the frames and data that best capture the events.

Shoemaker–Levy 9 observations are of very special significance for Galileo because they will constitute our first Jupiter science.

And now, quite literally, next stop...JUPITER!!!

— Bill O'Neil

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The Galileo Messenger

Issue 34 **June 1994**

Ida's Moon Discovered *(See related story next page)*

About 14 minutes before closest approach to Ida, this image was taken by Galileo's charge-coupled device (CCD) camera, illustrating the ~37 to 1 size difference between Ida and its moon (far right). Although the satellite appears to be "next" to Ida, it is actually slightly in the foreground. This image, along with the Near-Infrared Mapping Spectrometer data, helped scientists triangulate the bodies to determine that the satellite is about 100 kilometers from the center of Ida.

From the Project Manager

Galileo's interplanetary "science of opportunity" is nearing completion. It has far exceeded all expectations. Not only did we perform the second asteroid encounter, but that encounter with Ida resulted in the discovery of a satellite of Ida—the first ever sighting of an asteroid satellite. This is science of the first magnitude. And, what an interesting parallel with our namesake's discovery of Jupiter's satellites. In just a few more days, we will complete the playback of virtually all the high-priority Ida data from the spacecraft tape recorder right on schedule thanks to the excellent performance of the DSN, MOSO (Multimission Operations Systems Office), and the Galileo Flight Team.

For our final *en route* encore, Galileo will make the only direct line-of-sight observations of Comet Shoemaker–Levy 9 fragment impacts of Jupiter next month. Most of the Galileo Orbiter science instruments will attempt to measure the effects of these impacts. We have uplinked special software code patches to the visible imaging camera (on-chip-mosaicking) and to the spacecraft central computer (CDS) to help capture these temporally

—see page 9

Discovery of Ida's Moon Indicates Possible "Families" of Asteroids

Although Galileo flew by Asteroid Ida last August 28, some of the images it took are just now being transmitted and analyzed. That is why scientists were recently surprised to discover that Ida is not alone in space, but has a moon in orbit around it.

The discovery was first made by Ann Harch of the Galileo camera team, who noticed a bright object near Ida on some new images that were processed on February 17. The team considered and eliminated the possibility that the object was a planet, star, or something other than a moon. A few days later, the Near Infrared Mapping Spectrometer (NIMS) team also noticed some odd data while analyzing Ida's mineral content. They compared notes with the camera team and realized they had, indeed, found a moon.

Using images taken by the two Galileo instruments and comparing sighting angles at different times, the scientists determined the as-yet-unnamed moon is located about 100 kilometers from Ida's center. NIMS data also indicate that the rocks and soil on the surface of the tiny moon (only about 1.5 kilometers long) have roughly equal mixtures of olivine, orthopyroxene, and clinopyroxene, while Ida's surface is predominately olivine with a bit of orthopyroxene. The two are about the same temperature—200 K. More data are needed to determine the characteristics of the moon's orbit, which in turn will help to calculate Ida's density.

This close-up of Ida's 1.5-kilometer-wide moon is the most detailed picture of the recently discovered natural satellite of Asteroid 243 Ida taken by the Galileo Solid-State Imaging camera during its encounter with the asteroid on August 28, 1993.

Shortly after the discovery, Galileo scientists eliminated the idea that the moon is a passing body caught in Ida's gravity. They also doubt that the moon is a piece of Ida knocked loose by a smaller projectile, especially since their bulk compositions differ slightly. Instead, scientists are theorizing that the two are siblings of a "family" of asteroids formed hundreds of millions of years ago when a larger, 100-kilometer-wide asteroid was shattered in a great collision. Instead of fragments shooting straight out from the impact, the exploding asteroid may have produced jets of material carrying two or more objects out together. Those objects would then be captured, gravitationally, around each other. (See "How Can an Asteroid Have a Moon?" on page 4.)

Thus, a family of asteroids could have been created as a result of such an impact. Ida belongs to the Koronis family that travels in the main Asteroid Belt between Mars and Jupiter. Gaspra, the asteroid visited by Galileo in October 1991, is a member of the Flora family.

The discovery of Ida's moon "probably means they [asteroidal moons] are quite common," said astronomer Michael J. S. Belton, who leads the Galileo camera team. Many scientists suspect that a significant fraction of asteroids may have satellites. He noted that scientists believe they are on the verge of answering many questions about the existence and origin of asteroids and their satellites.

Galileo finished transmitting Ida data in June—including additional images of Ida's moon—and scientists expect to be able to determine more about the origin, composition, size, and orbit of Ida's moon, as well as the dynamics of collisions that played a central role in shaping the planets.

Messenger Available Electronically

You can now access the *Galileo Messenger* electronically over the Internet. From within Mosaic, type the following URL:

http://www.jpl.nasa.gov

This brings you to the JPL Home Page from which you can access the *Messenger*.

The latest information on Galileo can be found by selecting "News Flashes" from the Home Page.

If you have comments or suggestions regarding the *Messenger*, you can send email to:

Jeanne.M.Holm@jpl.nasa.gov

Up To Date

During this update period (January 1–June 15, 1994), the spacecraft performed operational activities associated with health and attitude maintenance, telecommunications link characterization, trajectory correction maneuvers, routine science memory readouts, data return from the Ida encounter, and the gravity wave experiment.

Ida Encounter

Four Reserved Box Sequences were uplinked to the spacecraft for the playback of Ida science data. Playback has continued throughout the spring, revealing much more from Galileo's flyby of the asteroid late last summer. An innovative procedure was developed in February and March to process data through the Mission Telemetry System (MTS). The procedure was developed in response to an MTS problem in which lockup occurred on compressed imaging frames sent in jailbox search memory readouts (MROs). The problem occurred because not enough frame headers were included in the sequence design of the MROs.

Data from the Ida encounter have been successfully received from all instruments (except the Heavy Ion Counter, which was not taking data), including almost 30 minutes of fields and particles data acquired just after closest approach. To date, over 98 percent of the data have been successfully received with only minor outages due to weather and short-term ground equipment problems.

Navigation

With the successful completion of Trajectory Correction Maneuver 22A on February 15, which imparted a 0.1-meter/second change to the spacecraft velocity, Galileo is now aimed at a point inside of Jupiter's atmosphere. To be precise, Galileo is targeted inside the atmospheric entry Probe's required entry corridor, which is defined by time of arrival, latitude, and flight-path angle. This is the desired situation, since the Orbiter is responsible for the precise delivery of the Probe, which is scheduled for release on July 13, 1995.

Gravity Waves

The gravity wave experiment ran from April 28 through June 11. Both closed-loop (Doppler tracking) and open-loop (radio science receiver) data were processed.

Routine Operations and Testing

Cruise Science

Six routine Retropropulsion Module 10-N maintenance flushing activities were completed. Regular science data acquisition from the Extreme Ultraviolet Spectrometer, Dust Detector, and Magnetometer has continued successfully in parallel with the Ida data return, using the Command and Data Subsystem (CDS) MRO technique. CDS MROs were also performed between January 15 and 20 to play back selected low-rate science data from the Ida encounter. Preliminary analysis has shown that the data were properly received.

Ultrastable Oscillator

Seven Ultrastable Oscillator (USO) tests were performed between January 4 and April 25 to verify the instrument's health and to collect gravitational red-shift experimental data. Long-term trend analysis is continuing.

Telecommunications—Block V

Six Block V receiver fast-acquisition tests were performed; all six were unsuccessful in demonstrating the Performance Verification Model receiver operation in the suppressed carrier mode. Troubleshooting on the receiver is now highly focused and successful operation is expected this fall.

Anomaly Status

AACS Ida Anomaly Test

Between January 22 and 25, Ida engineering data were played back using CDS MROs. Scientists used

—see page 8

Galileo Mission Summary*

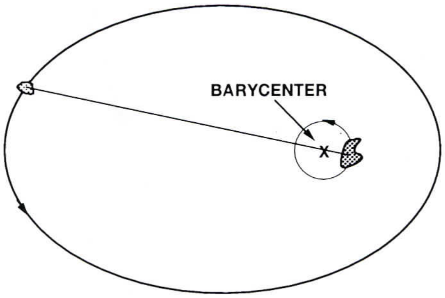
Distance from Earth	536,741,200 km (3.59 AU)
Distance from Sun	669,669,900 km (4.48 AU)
Heliocentric Speed	38,400 km/h
Distance from Jupiter	252,317,900 km
Round-Trip Light Time	59 min, 44 s
System Power Margin	44 W
Spin Configuration	Quasi all-spin
Spin Rate/Sensor	2.89 rpm/Star Scanner
Spacecraft Attitude	Approximately 7 deg off-Sun (leading) and less than 1 deg off-Earth (leading)
Downlink Telemetry Rate	40 bps (coded)
General Thermal Control	All temperatures within acceptable ranges
RPM Tank Pressures	All within acceptable ranges
Powered Science Instruments	Plasma Wave Spectrometer, Extreme Ultraviolet Spectrometer, Ultraviolet Spectrometer, Energetic Particle Detector, Magnetometer, Heavy Ion Counter, and Dust Detector Subsystem
RTG Power Output	505 W
Real-Time Commands Sent	73,306 commands

* All information is current as of June 15, 1994.

How Can an Asteroid Have a Moon?

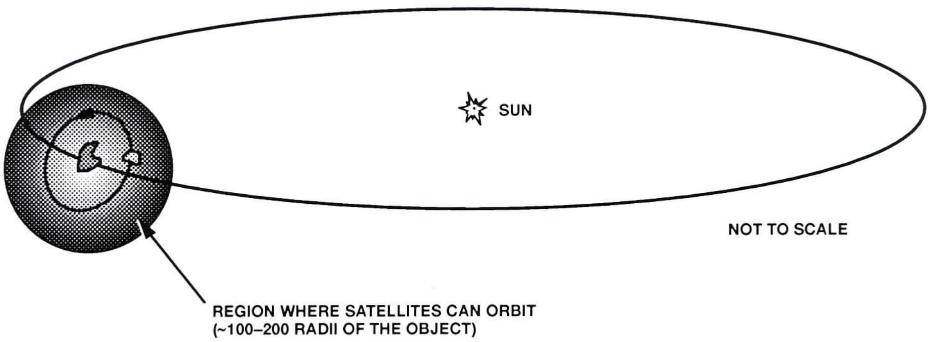
Sir Isaac Newton first described how any two objects, no matter what size or how far apart they are from each other, exert an attractive force upon one another. Since gravity is, relatively, a very weak force (compared to electricity and magnetism, with which we have familiar experiences), we don't recognize that tables, baseballs, buildings, and even people all gravitationally attract each other. These forces are fantastically small, but it is interesting to note that the gravitational attraction between a parent holding a child is stronger than that of any one of the planets (except Earth!) on that child. In other words, even an object with little mass can exert a greater force than another much more massive object, if the smaller object is much closer than the larger one. In mathematical terms, the force of gravity falls off as the inverse of the distance squared. So, if the distance between two objects is doubled, the attractive force is one-quarter the value.

Similarly, Ida and its moon attract each other. Because they are far from other bodies compared to their mutual separation, they influence each other very strongly. Any two bodies under the right circumstances will orbit each other, even if they also orbit about a third body, such as the Sun. (The Sun, of course, is in orbit about the Galaxy, which in turn is in orbit about other galaxies, and so on.) Bodies actually orbit about their mutual center of mass, called the barycenter, which is located along a line connecting their centers, and at a distance from either center inversely proportional to the mass of that object. Calculations have shown that asteroids like Ida can have satellites in stable orbits out to about 100 to 200 times their radius, so Ida could have satellites out to several thousand kilometers. However, only the one moon, 1993 (243) 1, has been seen as yet.



Any two objects, even if small and distant, will orbit one another if they are far from other objects.

— *Jan Ludwinski*
Mission Design
Team Chief



If a planet or asteroid is orbiting the Sun, the planet or asteroid can have a satellite if the satellite is close enough that the planet's or asteroid's gravity influences it more than the Sun's gravity.

Name That Moon!

There is no precedent for naming an asteroid's moon. Responsibility for naming Solar System bodies lies with the International Astronomical Union's (IAU) Working Group on Planetary System Nomenclature.

The Galileo Project is now soliciting names for Ida's moon, which currently carries the temporary designation 1993 (243) 1: 1993 is the year Galileo photographed it; 243 is the numerical designation of Ida; and the 1 notes that it is the first satellite discovered around Ida. The name chosen for Ida's satellite should relate in some way to Ida, either through mythology (Ida was a nymph who cared for the infant Jupiter) or similarity in name (Lupino has already been suggested—remember actress Ida Lupino?).

All suggested names and accompanying rationale for the choice must be received by the Galileo Project by **July 31, 1994**. The Project (through the Near Infrared Mapping Spectrometer and Solid-State Imaging teams) will then make a recommendation to the IAU in August. As the discoverers of the satellite, we trust that the IAU will give our recommendation special consideration.

Please send your suggested names to:

Name Ida's Satellite
Project Galileo
Mail Stop 264-419
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

We appreciate and will seriously consider all suggestions.

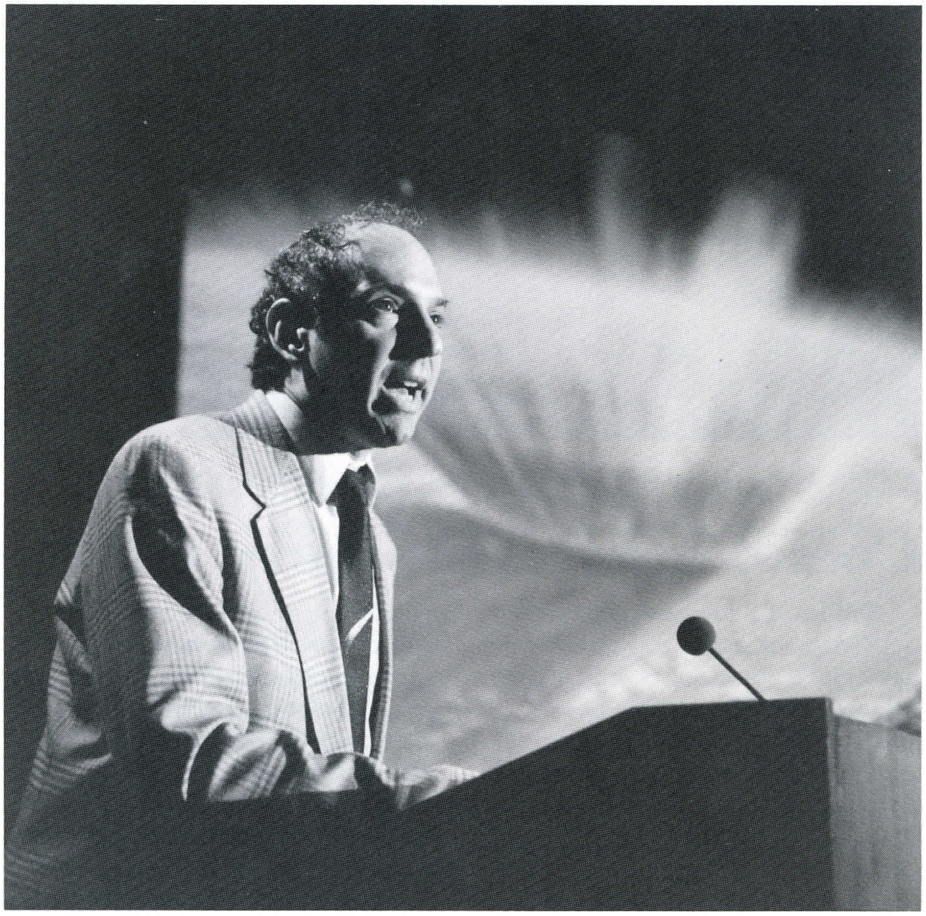
Comet Codiscoverer Speaks at JPL

Literary scholar and inveterate comet hunter David Levy, who is part of the team that discovered Comet Shoemaker–Levy 9 last year, discussed his exciting discovery at JPL's von Karman Auditorium on May 17. Levy used photographs, music, poetry, and humor to bring his subject to life.

As a young man, Levy became captivated by comets after reading *Starlight Nights*, the autobiography of famous comet hunter Leslie C. Peltier. To help explain "what makes a comet hunter tick," he shared the following excerpt from the book:

> *Time has not lessened the age-old allure of the comets. In some ways, their mystery has only deepened with the years. At each return, a comet brings with it the questions which were asked when it was here before, and as it rounds the Sun and backs away toward the long slow night of its aphelion, it leaves behind with us those questions still unanswered. To hunt a speck of moving haze may seem a strange pursuit. But, even if we fail, the search is still rewarding. For in no better way can we come face to face night after night with such a wealth of riches as old Croesus never dreamed of.*

Inspired by these words, Levy began his search for comets at age 17 using a small backyard telescope. Nineteen years later, after moving from Canada to Tucson for better viewing conditions, he was finally rewarded with his first comet discovery in 1984. Since then, he has discovered 20 more comets—8 from his own backyard and 13 with Gene and Carolyn Shoemaker at the Mount Palomar Observatory.



David Levy's talk at JPL was highlighted by dramatic illustrations of what the comet fragment impacts might look like at Jupiter.

His optimism and patience have really paid off this time. Levy recalled how poor the viewing conditions were that evening and how close they had come to calling off their observations. But when the sky cleared briefly, Levy talked the Shoemakers into using a few more sheets of some slightly damaged film. The next afternoon, Carolyn Shoemaker was methodically studying the pictures through her stereomicroscope when she saw the bizarre streak of light not far from Jupiter.

Their joint discovery of the luminous "string of pearls" comet caused a worldwide stir, even before its collision course with Jupiter was charted. Jim Scotti, an astronomer at the University of Arizona's Lunar and Planetary Laboratory in Tucson, confirmed their findings with the powerful 36-in. Kitt Peak telescope. Scotti was astounded; he told Levy, "I've been trying to pick my jaw up off the floor! I'm not taking my telescope off this comet for the rest of the observation period."

Although Levy is hesitant to predict spectacular fireworks when the comet collides with Jupiter, he is thrilled that it is capturing the public's imagination. "This is a marvelous opportunity to increase public awareness of what we [astronomers] do. For the first time in the history of the telescope, we are witnessing the impact of a comet on a planet. I still can't believe how fortunate we are to have this wonderful spacecraft [Galileo] available to us. It is so rare in science to have everything working together. This is truly an event of the first magnitude."

"The Cosmic Event of the Millennium"

Comet Shoemaker–Levy 9 to Crash Into Jupiter

Galileo will have a front-row seat in an extraordinary galactic performance beginning July 16 when Comet Shoemaker–Levy 9 (SL9) collides with the largest planet in our Solar System. The performance will last six days, as some 22 massive chunks of the comet crash into the atmosphere of Jupiter at the average rate of one every six hours. The comet broke into pieces two years ago when its orbit brought it close to Jupiter. This time, scientists anticipate that the impacts will result in large explosions, whose flashes may be visible directly to Galileo and which may be bright enough to be seen by Earth-based observers by reflection off Jupiter's closest moons. The largest piece will collide with the planet on July 20, coincidentally the twenty-fifth anniversary of the Apollo 11 landing on the Moon.

None of this was anticipated when Galileo was launched in October 1989. In fact, SL9 was discovered just over a year ago in March 1993, when astronomers David Levy and Gene and Carolyn Shoemaker spotted the comet from the Mount Palomar Observatory in California. Their discovery sparked the interest of others, and soon many telescopes were tracking the comet and computers were calculating its trajectory. These orbital investigations led to the surprising realization that SL9 was on a collision course with Jupiter.

As luck would have it, Galileo will be well poised to view the celestial fireworks, which will occur on the far side of Jupiter as viewed from Earth and on its night side. No other spacecraft (except Voyager 2, which is currently over 6 billion kilometers from Jupiter), including the Hubble Space Telescope, nor any Earth-based telescope will have that viewing advantage. Those telescopes will have to settle for observing indirect effects, such as the previously mentioned reflections or the aftermath of the damage as the impact areas rotate into view of the Earth. It is important to realize, however, that Galileo is still 240 million kilometers away from Jupiter, and the impacts—***if they are visible at all***—will be only a small dot of light in the Galileo images.

The Challenge and Payoff

Capturing the images and other science data is complicated by several factors, including the limited tape recorder space, the reduced downlink capability, the uncertainty in actual effects of the comet impacts (due to our poor understanding of its size), and the several-minute uncertainty in the actual impact time of each fragment. The science teams have adopted a strategy of using different observing schemes on different impacts so as to cover much of the uncertainty space. For example, the Solid-State Imaging camera will utilize four different schemes to measure light intensity from Jupiter. Scientists hope these data will reveal more about the composition of Jupiter's atmosphere, the origin of the comet, and the implications of a similar impact to our planet.

Some believe the collision will create giant bubbles of hot gas that will bring materials from far below Jupiter's thick cloud cover to the top, where those materials can be analyzed. Others think the impact could even cause changes in the planet's distinctive banded appearance or cause the birth of new spots.

How can a tiny comet have such an impact on the giant planet? "Comparing the mass of SL9 fragments to Jupiter is a bit like comparing a gnat with an elephant," writes Clark Chapman, a senior scientist at the Planetary Science Institute in an article for *New Scientist* (March 5, 1994). "But, just as . . . dust ejecta arising

A String of Pearls. *This composite image of the 22 fragments that make up Comet Shoemaker–Levy 9 was taken by the Hubble Space Telescope in January 1994. The comet was torn into pieces by Jupiter's gravitational pull as it passed the planet in 1992. The Planetary Report calls it "Jupiter's celestial necklace."*

from an impact on Earth changes global climate, so the impacts on Jupiter should profoundly affect that planet's stratosphere." Scientists point out that even a few cubic kilometers of comet ices can overwhelm the dynamics and chemistry of Jupiter's atmosphere locally.

Scientists also hope to learn more about the origin of SL9. From observations of the fragments' brightness and arrangement along their orbits, astronomers believe the comet must have measured between 3 and 9 km in diameter before it fragmented. They also believe that SL9 has been in orbit around Jupiter for 20 to 100 years. Since most comets orbit the Sun, this intriguing finding led to speculation that SL9 began life as either a small satellite of Jupiter, a so-called Trojan asteroid locked into Jupiter's orbit, or a comet captured by the planet's strong gravitational pull.

Ironically, if SL9 had not fragmented, astronomers would never have known it existed; it was too small, dark, and faint. But after its breakup, the long string of fragments and the dust associated with them presented a vastly larger surface area off which to reflect sunlight. When Carolyn Shoemaker first spotted the odd-shaped SL9, she thought it was a "squashed comet." Her team immediately notified colleague Jim Scotti in Arizona, who used a larger telescope equipped with sensitive charge-coupled devices and was able to determine that the object was actually a string of comet fragments.

Finally, SL9's crash will give astronomers a chance to actually witness a comet shaping a planet's future, a process that has been going on since the beginning of our Solar System. Nearly 200 large impact craters still exist on Earth, despite erosion and extensive plate tectonics that have erased many of them. Scientists say that every million years or so an asteroid or comet strikes our planet, which can drastically change our global climate. Every *hundred* million years, one strikes with a size and force that can actually change the course of evolution, like the 10-km-wide fragment that struck the Earth 65 million years ago and is believed to have wiped out the dinosaurs. What SL9 does to Jupiter will give scientists a better idea of what happened on Earth in the past.

Theories aside, "we've never seen anything hit a planet that is even as big as a house," according to Steve Marain, a spokesman for the American Astronomical Society, who was quoted in the April issue of *Aerospace America*. Several SL9 chunks may be as large as small mountains.

Worldwide Interest

Astronomers are comparing this event to the excitement generated by Halley's Comet, which captured the attention of millions of people around the world in 1986. The Planetary Society is setting up a worldwide network of observers to strive for constant coverage from ground-based telescopes during the string of impacts. Under the title "Jupiter Watch," the Planetary Society will publish guides, provide video links from telescopes to classrooms and television stations, and organize Jupiter Watch parties in order to educate the public about astronomy, space, and the origin of life.

All this attention can't fail to put the spotlight on Galileo, with its unparalleled view of the action and its ability to detect the effects of the SL9 impacts through several of its instruments. It will also focus attention on Galileo's arrival at the Jovian system on December 7, 1995, some 17 months after the collision.

(Updates on Jupiter Watch events can be obtained by calling 1-800-9-WORLDS.)

UP TO DATE from page 3

these data to study the anomalous attitude-control flight fault-protection trip that occurred hours before the Ida encounter on August 28, 1993. Using those data as a guide, an anomaly test sequence was designed to provide insight into the Attitude and Articulation Control Subsystem fault indications by rerunning key parts of the Ida encounter sequence. The test sequence ran from May 9 through 13 without any fault indication.

AC/DC Bus Imbalance

The alternating current (AC) bus imbalance measurement has remained fairly stable since March 1992 and currently reads 4.3 V.

The direct current (DC) bus imbalance measurement has shown significant change. On May 19, the measurement exhibited a gradual drop from ~17 V to near 12.5 V over a 36-hour period. On May 21, it abruptly increased from 12.5 V to near 22.5 V and has since remained stable. Other telemetry measurements also changed during the time period of the bus imbalance change, which included the DC bus current, AC bus current, system DC shunt current, CDS 10-VDC power supply current, SBA temperature, and USO oven current.

The AC/DC anomaly team was convened to verify that these telemetry changes are consistent with the slipping-brush debris model. Preliminary analysis indicates that all telemetry changes seem consistent with clearing a debris path in the SBA. The Project will be briefed on July 12, 1994.

Uplink Generation

The Project has approved the EJ-7 Cruise Plan, which will be executed by the spacecraft starting July 11. This sequence will include the Shoemaker–Levy 9 observations and some early data return.

Ground Data System

Transition from the MTS-based telemetry support to the new Multimission Ground Data System (MGDS)-based support is nearly complete. The MGDS telemetry capabilities, supplied by the Multimission Operations Systems Office, provide workstations for telemetry display and analysis to supplement digital television and printer telemetry display devices. A period of parallel operations started March 31, during which both MTS and MGDS telemetry displays were provided in the Mission Support Area for comparison. In May, MGDS data were declared prime for real-time mission support.

As of this writing, July 1 was the date for the real-time MSA to relocate from one building to another at the Laboratory. At that time, MTS support of real-time operations was to be decommitted. Some problems are continuing with the MGDS non-realtime product support, particularly with the support of imaging data products provided to the Multimission Image Processing System (MIPS). This is the interface used for processing imaging data after Data Memory subsystem MRO from the spacecraft (i.e., Ida images). Decommitment of the MTS–MIPS interface support will be deferred until problems with the MGDS interface are resolved.

GDS integration of the E2.0 software deliveries was completed. In addition to the MGDS telemetry capabilities, the E2.0 build provided Galileo Phase-1 GDS support capabilities.

The software associated with the E3.0 mission build was delivered. As part of the mission build, 12 program sets and two command databases were redelivered. The most significant new capability provided in the E3.0 software was support of the new SSI "on-chip mosaic" capability that will be first used during the Shoemaker–Levy 9 sequencing in July.

—*Matt Landano*
Deputy Mission Director

In Memory of James B. Pollack

James B. Pollack, world-renowned expert in the study of planetary atmospheres and particulates using nongrey radiative transfer techniques, died June 13 from a rare form of cancer. His work led to many advances in our understanding of the Solar System, including evolutionary climate change on all the terrestrial planets and detailed models of the early evolution of the giant gas planets.

Dr. Pollack participated in every major NASA flight mission since Apollo. He made fundamental contributions to the design, development, and implementation of the Mariner Mars series, Pioneer Venus, Viking, Voyager, Galileo, and Cassini, and was a key player in Mars Observer and CRAF. He was a member of the imaging teams of the Mariner 9 orbiter of Mars, the Viking Lander on Mars, and the Voyager spacecraft for the Saturn, Uranus, and Neptune encounters.

His discoveries include the first real evidence that the clouds of Venus are composed of sulfuric acid, and the resolution of a major paradox concerning Saturn's rings. He first conceived that nearly lossless scattering by wavelength-sized particles of water–ice could explain the low microwave emissivity and high radar reflectivity of Saturn's rings. Dr. Pollack also led a team in modeling the luminosity evolution of giant gas planets during their primordial contraction stages. These models were applied to explain the density gradient in the Galilean satellites as a natural outcome of their location relative to luminous proto-Jupiter.

Until his death, he was a senior space research scientist at the NASA Ames Research Center in California.

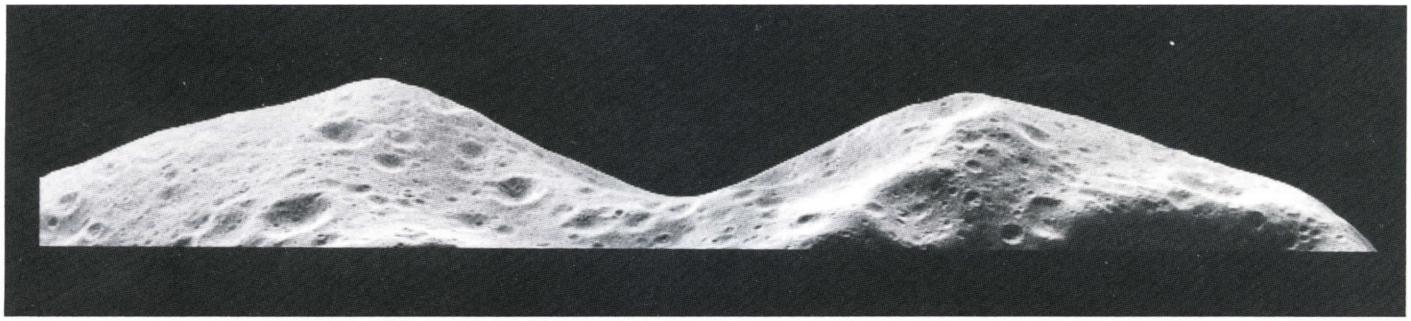
PROJECT MANAGER from page 1

elusive events. The difficulty is that there is tens-of-minutes uncertainty in when the impacts will occur. We must very judiciously program Galileo such that the limited amount of data we can store on the spacecraft for later playback has the best chance of "capturing" the events. Moreover, we can only play back less than 10% of what we record, so close collaboration with terrestrial observers of the aftermath effects will be needed to reduce the "post-facto" timing uncertainty to best determine what data to play back. The Shoemaker–Levy 9 impact observation experiment is much more elaborate and challenging than many of us originally envisioned. We begin uplinking the first phase of the new flight software for Jupiter operations in February so all playback must be completed before then.

The development of the new capabilities for Jupiter operations on the Low-Gain Antenna has been underway for well over a year now and is right on schedule. Over the past several months, the overall Project focus has been shifting to Jupiter preparations. Clearly, proper release of the Probe (July 13, 1995) and successful Probe Relay and Jupiter Orbit Insertion (JOI) on December 7, 1995, are our top priority. From now until JOI completion, we will be most vigilant to ensure that no other Project activities adversely affect our preparations for these absolutely essential events. The preparations include thorough testing of the recently completed new flight software for Relay/JOI (Phase 1) on our Galileo Spacecraft Testbed using the exact sequences that will be sent to the spacecraft. The "critical" sequence that will perform Relay/JOI, as well as the "noncritical" concurrent sequence for collecting arrival day science, are both now in development. In the event of a fault, the "noncritical" sequence will be automatically cancelled by the spacecraft to provide the best chance for successful completion of the "critical" sequence. The "noncritical" sequence will be completed and "frozen" this fall; the final version of the "critical" sequence, next summer. Concurrent development and testing is being done to maximize the reliability and robustness of the flight software and sequences.

While second in priority to Relay/JOI, our biggest effort from here on is Jupiter orbital operations preparations. Development and testing of the new flight and ground software for orbital operations (the Phase 2 software) will be ongoing until late 1995. Next month, we begin the detailed development of the actual spacecraft sequences that will use the Phase 2 flight software to issue the commands onboard the spacecraft to acquire and return the science data during the two-year primary orbital mission of 11 orbits, with targeted Galilean satellite gravity-assist encounters on all but one. The sequence development is scheduled on a "just-in-time" basis to minimize cost. It takes far more time to develop the sequences for an orbit than a typical Galileo orbital period (weeks); we must start now in order to complete the sequences for the final orbit just before they must be sent to the spacecraft. We have a lot to do. We must very carefully manage all our resources—people, spacecraft, and money—to get it all done.

In the last *Messenger*, we noted our puzzlement that a bus reset had occurred in all-spin last September. A very sophisticated computer analysis of the Spin Bearing Assembly (SBA) brush/



The Galileo imaging system captured this picture of the limb of Ida about 46 seconds after Galileo's closest approach on August 28, 1993, from a range of 2480 kilometers. It is the highest resolution image of an asteroid's surface ever captured, showing detail at a scale of about 25 meters per pixel.

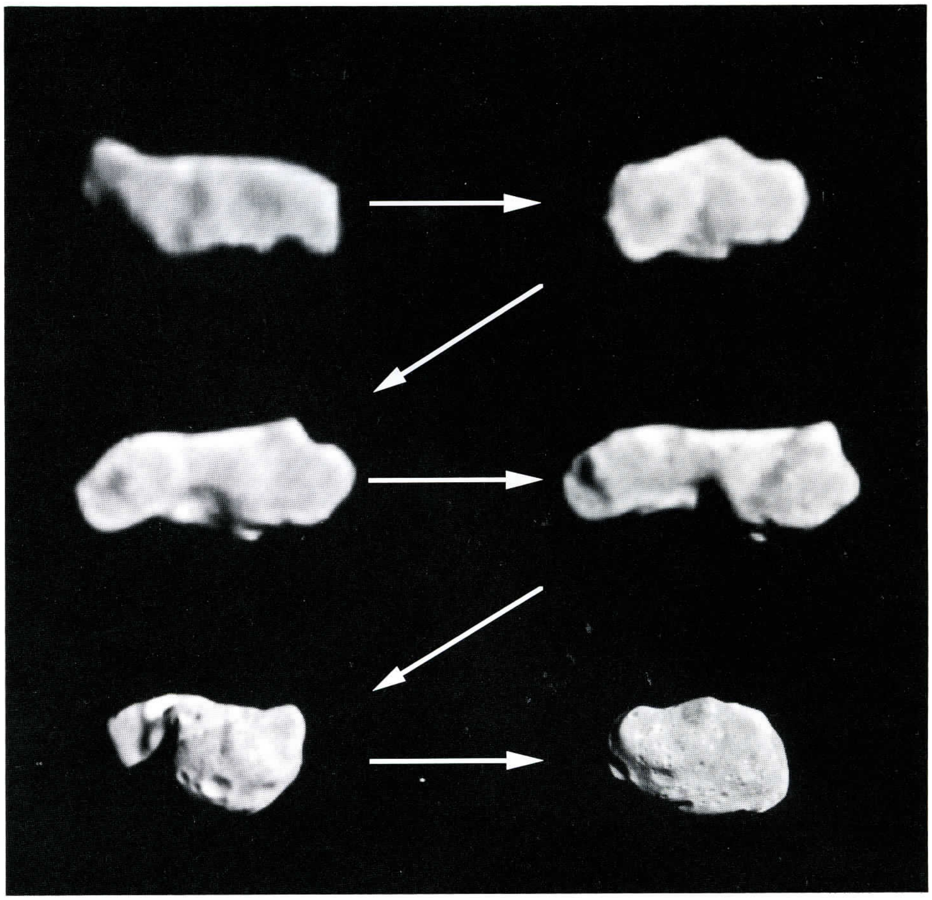
This image is one frame of a mosaic of 15 frames shuttered near Galileo's closest approach to Ida. Since Ida's exact location was not well known prior to the Galileo flyby, this mosaic had only about a 50 percent chance of capturing Ida. Fortunately, this single frame successfully imaged a part of the sunlit side of Ida.

The area in this frame shows some of the same territory seen in a slightly lower resolution full-disk mosaic of Ida returned from the spacecraft in September 1993, but from a different perspective. Prominent in this view is a 2-kilometer-deep "valley" seen in profile on the limb. This limb profile and the stereoscopic effect between this image and the full-disk mosaic will permit detailed refinement of Ida's shape in this region. This high-resolution view shows many small craters and some grooves on the surface of Ida, which give clues to understanding the history of this heavily impacted object.

ring dynamics solved the puzzle. Mechanical dither between the spun and despun spacecraft sections occurs due to the tolerance in the active control loop that operates the SBA torque motors to keep the sections fixed with respect to each other. The dither causes the brushes to rock on the slip rings due to the very slight back and forth motion of the ring surface under each brush. When a brush rocks up on its leading edge (toe) or back on its trailing edge (heel), the electrical contact surface between the brush and ring is drastically reduced—effectively opening the circuit. Thus, the all-spin dither-induced rocking effectively produces the brush "lifts" (i.e., bounce) we have long believed to be an essential part of the spurious bus resets. So, all nine of our resets "fit" the SBA brush-debris-short/brush lift model. Recall that the Relay/JOI critical sequence continues even if a reset occurs, and our new orbital operations (Phase 2) flight software is being built so that any sequence will continue.

Our comprehensive review of the Mars Observer (MO) investigation reports has been completed and endorsed by a select, non-Galileo Review Board. Galileo is very different than MO in heritage, design, FMECA, testing, etc. More specifically, it was objectively concluded on an item-by-item basis that Galileo is not susceptible to the postulated MO failure types. However, the MO loss is causing us to be even more circumspect in our final review of the normal and contingency operating modes of Galileo's 400-N main engine that will be used for the first time to perform the Orbiter Deflection Maneuver (ODM) shortly after Probe Release next summer.

— *Bill O'Neil*
Project Manager



This composite image shows Ida as seen from Galileo during its approach on August 28, 1993. The asteroid makes a complete rotation every 4 hours 38 minutes; therefore, this set of images spans about three-quarters of Ida's rotation period and shows most of Ida's surface. The asteroid appears to be about 58 kilometers long and about 23 kilometers wide, with a very irregular shape and volume of some 16,000 cubic kilometers.

Beginning in the upper left, the images are arranged in chronological order from a time 3 hours 51 minutes before closest approach through 33 minutes before closest approach. Ida's rotation axis is roughly vertical in these same-scale images, and the rotation causes the right-hand end of Ida to move toward the viewer as time progresses. The first image was taken from a range of about 171,000 kilometers and provides an image resolution of about 1700 meters per pixel (the highest resolution achieved for Ida is about 25 meters per pixel). The second, taken 70 minutes later, is from 119,000 kilometers, followed by 102,000; 85,000; 50,000; and 25,000 kilometers. The features on Ida are less sharp in the earlier views because of the greater distances.

Prominent in the middle views is a deep depression across the short axis of the asteroid. This feature tends to support the idea that Ida originally may have been formed from two or more separate large objects that collided softly and stuck together. Also visible in the lower left view is an apparent linear albedo or reflectance boundary. Color images yet to be returned from the Galileo spacecraft may help resolve the question of whether or not the two ends of Ida are made of different materials.

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Galileo Messenger Readers' Survey

In an effort to improve the *Galileo Messenger* and its usefulness to readers everywhere, we are asking you to take a few minutes to complete this survey. The results will be published in a future issue. Our return mailing address is on the reverse side. Simply fold, staple shut, attach appropriate postage, and mail by August 15, 1994.

1. How do you read this newsletter?
   - ☐ Read all or most
   - ☐ Scan headlines and only read those articles of interest
   - ☐ Scan quickly
   - ☐ Do not read
2. Check the categories of articles of interest to you in your order of preference (1 being of most interest):
   - ☐ Highly technical scientific information
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   - ☐ In-depth explanation of scientific concepts relating to Galileo's mission
   - ☐ Commentary from the Project Manager
   - ☐ Description of routine spacecraft operations
   - ☐ Other ______________________________
3. Please answer each question:

YES	NO	
☐	☐	Do you discuss the content of the Galileo Messenger with colleagues?
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4. What best describes your job function or department (check one)?

☐ Scientist/Engineer	☐ Education/Training	☐ Accounting/Finance
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We would appreciate any further comments you might have (use another piece of paper, if necessary):

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Teachers and educators are asked to complete this section of the survey:

9. Grade level or subject taught ______________________________

10. How could the Galileo Messenger format be changed to be of better use as a teaching tool?

____

11. List the types of articles that have been useful in the past

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12. I would like to see:

- [ ] More charts and other graphics
- [ ] A question-and-answer column (please suggest topics below)
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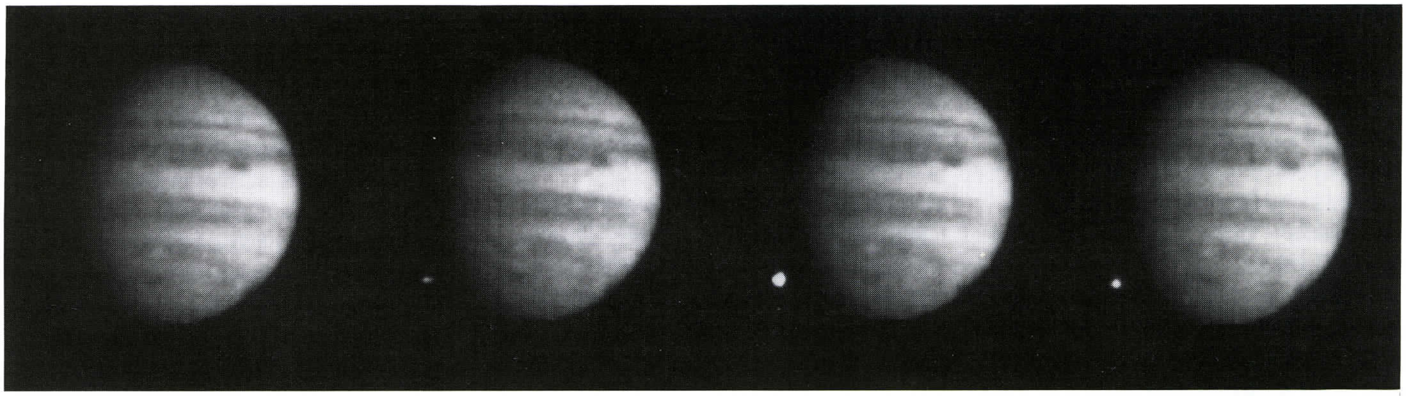
The Galileo Messenger

Issue 35 | December 1994

The Brilliant Death of Comet SL9



***Fragment W Impact**—The impact of Fragment W on Jupiter is shown in this series of Galileo images taken at 2.3-s intervals. No contact is visible in the first image. In the next three images, a point of light appears, brightens, and—7 seconds after the first image was taken—fades. Scientists are not yet sure whether the point of light is the fragment hitting Jupiter's atmosphere or the subsequent explosion and fireball. (P44542)*

What happens when a comet crashes into a planet? This past summer, the world finally found out when comet Shoemaker–Levy 9 (SL9) plunged into Jupiter, a gas giant eleven times Earth's radius and more massive than the rest of the planets put together. Despite Jupiter's huge size, the relatively tiny comet fragments made a spectacular impact, exceeding even the most optimistic predictions. As the world watched, some unexpected effects were observed—including fireballs hotter than the Sun, high plumes, and huge new dark patches, some rivaling the Great Red Spot in size.

In late October, preliminary data analyses from three of Galileo's instruments indicated that one of the SL9 fragments exploded into a 7-km (4-mile)-diameter fireball. This Fragment G fireball on July 18, when first detected by the Ultraviolet Spectromete (UVS) and Photopolarimeter-Radiometer (PPR), was about 8,000 kelvins (14,000 degrees Fahrenheit), which is hotter than the Sun's surface. Five seconds later, the Near-Infrared Mapping Spectrometer (NIMS) detected it, recording the fireball's expansion, rise, and cooling for a minute and a half, until it was hundreds of kilometers across and only about 400 K (260 deg F). Galileo has thus provided a unique data set on SL9, that is, the only profile of the size and temperature of the fireball

—see page 2

From the Project Manager

We are now just one year from Jupiter arrival on December 7, 1995. All our interplanetary targets of opportunity are well behind us and each was observed with grand success. Ida data return was completed as planned in June. Galileo's unique direct observations of Comet Shoemaker–Levy 9 fragment impacts in July are providing invaluable additions to the Earth-based observations' data set. The exact impact time and evolution of several of the major events have been determined by Galileo data. Data return is now suspended for three weeks around our December 1 solar conjunction. The balance of the planned return will be between mid-December and the end of January. The Deep Space Network (DSN) has captured over 98 percent of the Galileo SL9 data downlinked to date!

SL9 data return was also suspended as planned from mid-August to mid-September to perform a check of the functionality of every memory cell in Galileo's Command and Data Subsystem (CDS) extended memo-

—see page 12

during the first few minutes following the impact itself.

Observing Strategy

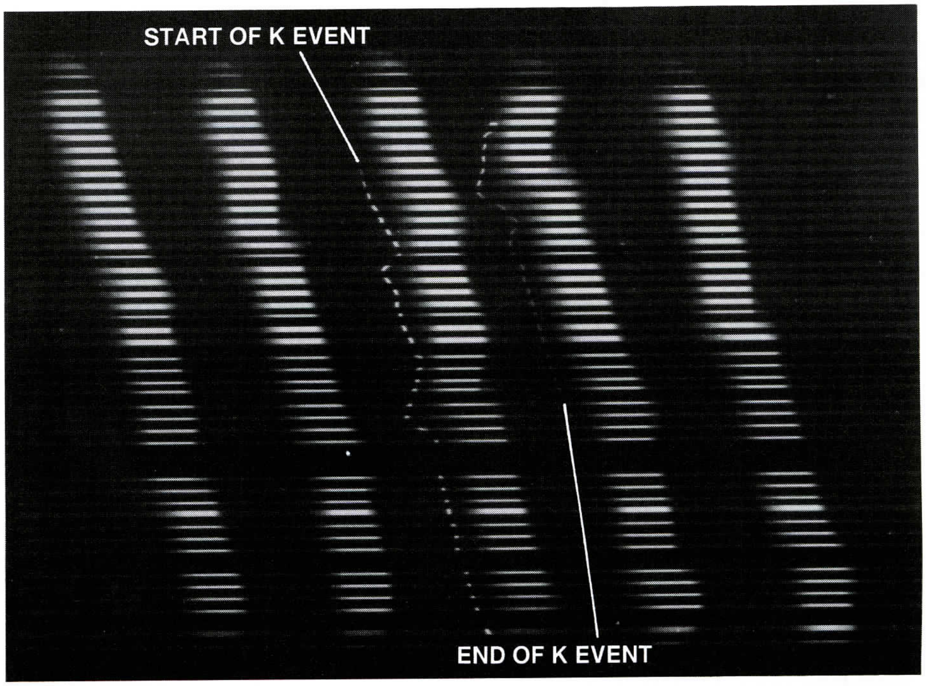
Five of the Galileo Orbiter's 11 instruments observed the comet impacts. The remote-sensing instruments mounted on the scan platform were four of the five—the Solid-State Imaging (SSI) camera, NIMS, PPR, and UVS. The fifth was the Plasma Wave Subsystem (PWS), included because it might be able to detect radio-frequency emissions caused by the impacts. A sixth instrument, the Dust Detector Subsystem (DDS), was configured to watch for any dust streams coming from Jupiter, which could take 1 to 2 months to reach Galileo.

The normal Galileo observing strategy is for a single instrument to be prime for a given observation, and other instruments to ride along where practical. However, there were unique constraints on the SL9 sequence development, particularly in staffing and budget. Observational opportunities were simply divided up between the four instruments (NIMS, SSI, PPR, and UVS) with most of the opportunities being assigned to the SSI and NIMS because of the anticipated likelihood of success. Most of the PPR observations were designed to provide near-real-time data return to help determine impact times. For all but one PPR observation, data were stored directly in the spacecraft's central computer and played back to the ground on a nearly daily basis. A similar approach was used for the PWS, which observed nearly continuously from before the first impact through the entire sequence with data being returned in near real time.

Of the PPR-observed events, nothing was seen on B; a clear signal was seen for G, H, and L; a faint signal was detected for Q1; and S was missed as a result of an out-of-tolerance shift in the time of impact. After preliminary processing of the PWS data, no impact-induced signals have been detected. SSI captured the K, N, and W fragment impacts. The NIMS, UVS, and PPR have returned data on the G event, where the huge fireball was measured. The PPR and SSI data so far indicate that the impacts produced near-infrared signals lasting a surprising 20 to 40 seconds with intensities ranging from 1 to 10 percent of the total brightness of Jupiter (for Q1 and K, respectively). As of late November, only data from impacts W and R remain scheduled for playback.

A Fascinating Riddle

One of the fascinating riddles that SL9 posed is why the Hubble Space Telescope and Earth-based observers saw some of the impacts *at the same time* Galileo did. When the observations were made, Galileo was at a viewing angle that should have allowed it to observe early events hidden from the Earth by Jupiter's horizon. One possible explanation for the simultaneous observations is that "something was happening high enough to be seen beyond the curve of the planet," speculates Dr. Torrence V. Johnson, Galileo Project Scientist. However, he points out that how the material got there is another question. "There may have been earlier, smaller impacts going on that were too faint for Galileo to detect that sent plumes high into the upper atmosphere, from which the main G impact fragment flash was reflected. Or it is possible that the main flash was reflected off of a train of dust that was following the main G fragment. We will learn more as our modeling continues."



K Impact Data*—To construct an accurate time history of the brightness of the K impact, the SSI camera took five separate 25.6-s exposures of Jupiter on July 19. In the first exposure at far left, the camera positioned Jupiter at the top of the frame, then scanned until Jupiter was in the bottom of the frame. It then repositioned Jupiter at the top of the frame and took four more exposures. The bright spots seen along the third and fourth row are the actual flares from the K impact. From top left to bottom right, the times of the exposures ran from 10:23:12 to 10:25:39 UTC (Universal Time Coordinated), which are equivalent times to when the event would have been observed on Earth. The horizontal bar pattern is a result of playing back only 2 or 4 image lines out of every 8, so as to reduce data quantity because of the very low data rate available. (P44880)*

Contradictory Implications

One question that Galileo may help answer concerns the size of the comet fragments. Were they large, several kilometers in diameter, as some predicted? Or were they much smaller—only half a kilometer across—or even just loosely held-together piles of rubble or wisps of dust?

A related question is how deeply the comet pieces penetrated into Jupiter's atmosphere before exploding. Single, large, solid fragments would have been expected to penetrate further and bring up water from Jupiter's presumed water-rich atmospheric layers, while rubble piles or rubble swarms might only have caused meteor storms in the upper atmosphere with no deep penetration. Preliminary spectroscopic data imply that the fragments *did not* penetrate very deeply, since little or no water was splashed up into the stratosphere. However, the spectacular show argues in favor of the large-fragment, deep-plunging model.

Another interesting question is why Jupiter's icy satellite Europa did not reflect the bright flashes from the dark side of Jupiter, as expected. Europa's shadowed, reflective, icy surface should have served as an excellent mirror for the brilliant flashes and subsequent glowing fireballs. But it didn't happen that way. As the recent information about the Fragment G fireball proves, Galileo may be best able to answer questions about optical flashes.

Perhaps the most perplexing question is what caused those immense black patches to remain in Jupiter's high atmosphere. The largest patches are much bigger than the whole planet Earth and much darker and more prominent than the Great Red Spot. Initially, they were expected to fade and disappear in a few days, but they seem to be persisting. Conceivably, as Galileo nears its target, it will also be able to help explain these aspects of the SL9 impacts at Jupiter. ■

Timing Is Everything

In planning Galileo's stored sequence for the SL9 observations, timing was the single most important factor. Normally, when designing a science observation, there is very little uncertainty about the observation time. Instead, the uncertainty is in the orbital motion of the target (or target ephemeris) and instrument-pointing accuracy. A common solution is to design a mosaic that covers an area large enough to make sure that the target is observed.

The comet impact observation sequence was effectively the opposite—neither target motion nor instrument-pointing accuracy were significant issues. Instead, the timing of each event was uncertain to tens of minutes. This posed a significant challenge to the Galileo science planners, since the sequences were very complex and could not be fully updated as impact time estimates changed.

In response, up to a 2-h observation window was designed for each impact event, during which instruments would point, operate, and take data. Then a 1-h window, which was moveable at a later juncture, was placed within this observation window for the actual recording of data. In addition, the Project implemented a new Galileo SSI capability—*on-chip mosaicking*—earlier than intended. The significant advantage of this capability is that many more images could be stored for the tape space cost of one frame. For the SL9 observations, 60 Jupiter images were stored per frame.

An additional challenge was the playback of the impact phenomena. Most of the observation data were stored on the tape recorder, which holds the equivalent of ≈130 SSI full-resolution images, but due to the 10-bps telemetry limitation, only about 5 percent of the tape could be returned in the time available. So the problem was knowing where to go to on the tape to retrieve data for playback.

As Jan Ludwinski, Chief of Mission Planning, explains, "Galileo recorded imagery and other spectroscopic information from the SL9 impacts with Jupiter on its 4-track digital tape recorder. This tape recorder holds up to 900 MB of data—over 900 floppy disks—which would take over 1000 continuous days to play back at 10 bits per second! But that calculation implies that all bits on the tape recorder contain valuable information, which is not true.

"Even though the impact events were expected to last only a few minutes, the uncertainty in the impact times *at the time of the sequence design* were as much as an hour or more. That meant Galileo had to record 20 to 30 times longer than an impact event itself just to be sure that it wouldn't miss the fireworks. *After the impacts occurred*, Galileo planners knew approximately where to search for the data on the tape recorder by using timing from Earth-based telescopic observations. By searching in this way, they avoided playing back tape-recorded data that had no impact information. So, instead of 900 MB, the actual amount of data to be returned is 20–30 MB. Allowing for interruptions for engineering activities and solar conjunction, playback of SL9 science data will be completed by the end of January 1995."

There are plans for faster data return during Galileo's prime mission, Jan notes. "As a preview of the power of the new operating software, which will be sent to the spacecraft in 1996, it will only take a few days to play back an equivalent amount of information during Galileo's tour of Jupiter's system!"

Solving for Dactyl's Orbit and Ida's Density

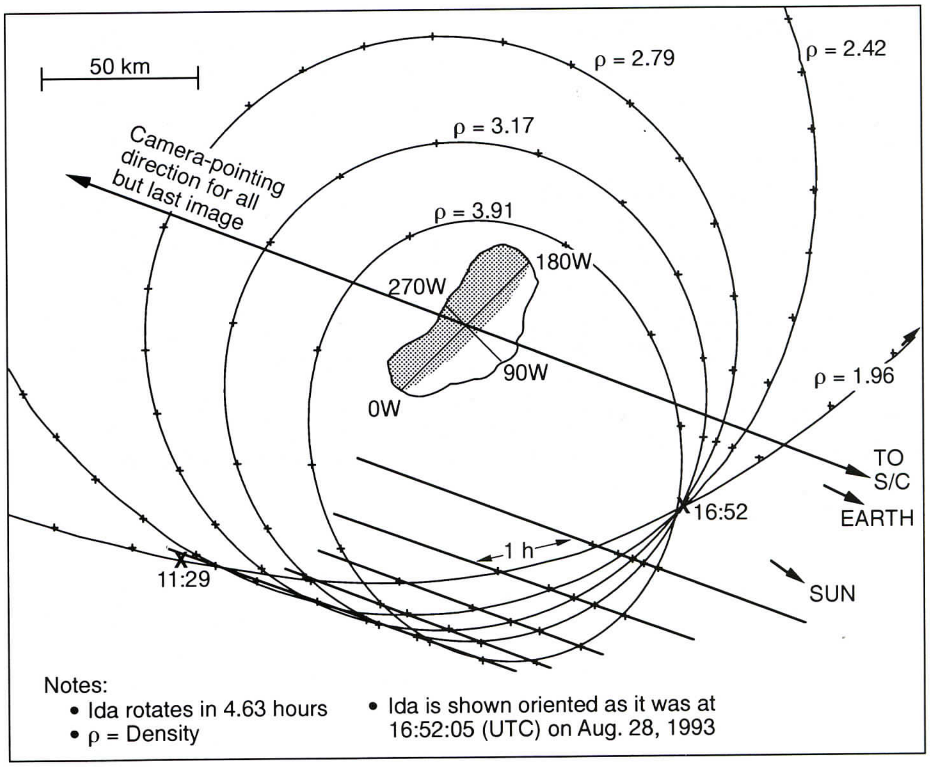
Galileo's recent discovery that Ida has a satellite (now known as Dactyl) suggests that satellites orbiting asteroids may be a commonplace occurrence. In the Solid-State Imaging (SSI) camera data returned from the Ida encounter, Dactyl and Ida appear in 47 images. Their locations in these images were used to estimate Dactyl's orbit and Ida's bulk density, which is of great interest because it may indicate whether Ida is composed of rocks that have been thermally processed deep within a collisionally destroyed planetesimal. Density calculations were based on an Ida volume of 16,100 km^3 (±12 percent), which was determined from an accurate model of the shape of Ida. While Dactyl's orbit is of interest, its greatest significance is in providing the first accurate estimate of an S-type asteroid's density—another achievement by Galileo!

Initial attempts to apply classical astronomical orbit-fitting methods to estimate Dactyl's orbit, assuming a reasonable value for Ida's density, suffered from numerical problems caused by the Galileo-to-Ida line of sight being nearly in the plane of Dactyl's orbit for most of the images. Mike Belton, SSI Team leader, then asked the Navigation Team to apply their orbit-determination methods to the problem, which led to this challenging and enjoyable search.

Since our objective was to determine preliminary estimates for Dactyl's orbit and Ida's density, the analysis was simplified by assuming that Dactyl's orbit was affected only by Ida's gravity acting as a point mass. The problem was to find an orbit for Dactyl that was consistent with the locations of Ida and Dactyl in the SSI images. Much of the analysis involved reducing the raw data associated with the images (exposure time, camera-pointing direction, positions of Ida, etc.) to a form usable by a new computer program that could estimate Dactyl's orbit. Another large part of the task involved actually writing and debugging this new program, which is constructed of QUICK commands. (QUICK is an easy-to-use, versatile processor from JPL's Multimission Analysis Software Library.)

It became clear almost immediately that the mass/density of Ida could not be solved at the same time as Dactyl's orbit. Instead, a series of Dactyl orbits were generated for a range of Ida mass/density values—from 1.5 to 4.0 grams per cubic centimeter (g/cm^3). For each density value, there is a unique orbit; over this range of densities, these orbits differ greatly. For Ida densities less than about 2.1 g/cm^3, the orbits are just barely hyperbolic. For higher Ida densities, the orbits are elliptical with a large apoapsis (farthest point from Ida), a periapsis (nearest point to Ida) of around 80–85 km, and periods that range from just over a day to many tens of days. At a density of about 2.8 g/cm^3, the orbit is nearly circular (about 82 × 98 km) with a period of about 27 hours. For even higher densities, the elliptical orbits have apoapses of about 95–100 km, with periapses that decrease with increasing density. For an Ida density greater than about 2.9 g/cm^3, the periapsis is less than about 75 km and the period is less than 24 hours. The geometry for a range of orbit solutions is shown in the accompanying figure. Since this view is from the spin pole of Ida, the motion of Dactyl and Ida's rotation are both counterclockwise.

The figure shows that when points recorded at the same time on each Dactyl orbit are connected, they are parallel to the center line through Ida that points to the spacecraft. All of the images but the very last were taken when Galileo was thousands—or even hundreds of thousands—of kilometers from Ida and nearly in its equatorial plane, so that the



Possible Dactyl orbits from Ida's south (spin) pole.

Dactyl by Idashine*—Within seconds of its closest approach to Ida on August 28, 1993, Galileo captured this SSI image of Ida's previously unknown moon orbiting the asteroid. The dark side of this moon is illuminated by light reflected from the sunlit side of Ida, in the same way that Earthshine brightens the dark part of Earth's Moon when only a thin sunlit crescent shows. (P44298)*

spacecraft was viewing the Ida–Dactyl system from the lower right part of the figure. For scale, the long axis of Ida is 58 km, and Ida is shown as it would be oriented at the time of Galileo's closest approach. Thus, the figure only covers a few hundred kilometers around Ida.

The last image mosaic was taken when Galileo was almost at its closest approach to Ida and included parts of both Ida and Dactyl in separate images. At that point, Galileo was essentially looking down on Dactyl's orbit plane (essentially the plane of the figure), and Dactyl was at the point where all possible orbits cross. The lowest parallel line connects the points on each orbit at 5 hours prior to closest approach, or about the time of the earliest image. Since Dactyl was viewed for only a fraction of its orbit and from a nearly edge-on vantage point, all of the orbits shown fit the observations equally well. If one imagines being on the Galileo spacecraft looking at Ida and Dactyl, then all of the orbit solutions would have appeared the same during the 5-hour approach, since the differences between them are all along the line of sight (the parallel lines in the figure).

Thus, for a given mass/density of Ida, a unique and well-determined two-body conic orbit can be found. However, this alone does not help us find the unknown density of Ida. Only by applying the dynamics of motion about a non-point-mass Ida and using our knowledge of the general distribution of asteroidal material in the entire asteroid belt can the range of possible mass/density values for Ida be reduced.

Dynamical studies show that orbits with periapses less than about 75 km from Ida are unstable and either collide with, or escape from, Ida—thus, orbit solutions are not physically possible that correspond to an Ida density of about 2.9 g/cm^3 or greater. At the other extreme, hyperbolic and even highly elliptical orbits around Ida are very unlikely. The observed speed of Dactyl around Ida for any of the orbit solutions is no more than about 10 m/s, about the speed of a fast run or a slowly thrown baseball. Calculations indicate that the chance of a random piece of asteroidal material the size of Dactyl passing by Ida at that speed, just when Galileo was observing it, are about 1 in 10^{19}. In addition, if Dactyl were in a hyperbolic or highly elliptical orbit, it should have been seen by the Hubble Space Telescope (HST) when it observed the region around Ida over an 8-hour period on April 26, 1994 . HST would have easily seen Dactyl had it been more than about 700 km from Ida. Combining these two restrictions gives a preliminary estimate for Ida's density of 2.1 to 2.9 g/cm^3. Allowing for a 12-percent uncertainty in the modeled volume of Ida increases the range to 1.9 to 3.2 g/cm^3.

This density range is surprisingly well constrained and suggests that Ida is fairly porous and/or made of fairly light rocks. This result already excludes several classes of dense igneous rocks that had previously been suggested as the primary components of Ida's composition.

Further work on the long-term stability of orbits that fit these observations, as well as a more precise analysis of the SSI images themselves, may lead to a better determination of both the density of Ida and the orbit of Dactyl. These, combined with other ongoing work involving the color, spectral properties, and geology of Ida's surface are expected to lead to major advances in our knowledge of the nature of asteroids and what they can tell us about the birth of the planets. ■

—Dennis V. Byrnes
Louis A. D'Amario
Galileo Navigation Team

Ida's Moon Named Dactyl

Congratulations to *Messenger* reader, Phil Stooke of the University of Western Ontario, who suggested the name Dactyl for the tiny moon discovered last February in orbit around the asteroid Ida. As discoverers of the moon, the Galileo Project had the honor of recommending a name to the International Astronomical Union, which approved the name Dactyl this fall. The tiny moon is the first natural satellite of an asteroid ever discovered and photographed.

The name is derived from the Dactyli, a group of Greek mythological beings who lived on Mount Ida, where the infant Zeus was hidden. In some accounts, Zeus—whose Roman name is Jupiter—was raised by the nymph Ida and protected by the Dactyli.

We appreciate the many suggestions from our readers.

Up To Date

During the last six months (June 6 to November 25, 1994), the spacecraft finished data return from the Ida encounter, recorded and returned data from the Comet Shoemaker–Levy 9 collision with Jupiter, continued a solar wind scintillation experiment, attempted to free the stuck ribs on the High Gain Antenna, and performed operational activities associated with health, attitude maintenance, and telecommunications link characterization.

Ida Encounter

Ida science data return was completed on June 26, 1994. Overall, 98.7 percent of the Ida science data transmitted by the spacecraft were successfully received and processed through the ground data system during the 1994 Ida data playback campaign.

SL9 Observations/ Data Return

Please see the feature article on page 1 for a complete summary of SL9 activities.

Dust Stream From Jupiter?

On June 25, the Galileo Dust Detector Subsystem (DDS) registered an increase in the rate of dust impacts reminiscent of the 11 dust streams that Ulysses detected coming from Jupiter. The particles had a mean impact speed of 17 km/s. Observations will continue and further analysis is planned.

Solar Wind Scintillation Experiment

Data collection on the solar wind experiment is scheduled to continue through December 28, 1994. This experiment is designed to measure the charged-particle environment very near the Sun by measuring the effect of those particles on the radio signal beamed from Galileo to Earth.

Routine Operations and Testing

Several routine Retropropulsion Module 10-N maintenance flushing activities were completed. Regular science data acquisition from the Extreme Ultraviolet Spectrometer, DDS, and Magnetometer has continued successfully in parallel with SL9 data return, using the Command and Data Subsystem (CDS) Memory Readout (MRO) technique. Several Data Management Subsystem conditioning activities were performed.

Ultrastable Oscillator

Seven Ultrastable Oscillator tests were performed to verify the instrument's health and to collect gravitational red-shift experimental data. Long-term trend analysis is continuing.

Acquisition Sensor

The Acquisition Sensor was routinely calibrated.

EPD Motor Maintenance

Two Energetic Particle Detector motor maintenance exercises were performed, which stepped the motor through its eight operating positions and then returned it to the normal position (Sector 4). The motor maintenance was successfully verified by an MRO.

Command Tests

Conjunction command tests were performed at Sun–Earth–spacecraft (SEC) angles ranging from 10.0 to 6.0 degrees. The command modulation was turned on at the station (DSS-63) and the spacecraft-received signal was monitored to see if the Command Detector Unit (CDU) locked up

Galileo Mission Summary*

Distance from Earth	887,483,800 km (5.9 AU)
Distance from Sun	740,842,400 km (5.0 AU)
Heliocentric Speed	31,300 km/h
Distance from Jupiter	187,404,500 km (1.3 AU)
Round-Trip Light Time	98 min, 42 s
System Power Margin	42 W
Spin Configuration	Quasi all-spin
Spin Rate/Sensor	2.89 rpm/Star Scanner
Spacecraft Attitude	Approximately 1 deg off-Sun (leading) and 2 deg off-Earth (leading)
Downlink Telemetry Rate/Antenna	10 bps (coded)/LGA1
General Thermal Control	All temperatures within acceptable ranges
RPM Tank Pressures	All within acceptable ranges
Powered Science Instruments	Plasma Wave Spectrometer, Extreme Ultraviolet Spectrometer, Ultraviolet Spectrometer, Energetic Particle Detector, Magnetometer, Heavy Ion Counter, and Dust Detector Subsystem
RTG Power Output	502 W
Real-Time Commands Sent	171,798 commands

* All information is current as of November 23, 1994.

and maintained lock. Preliminary results show that the CDU stayed in lock throughout the tests, though further analysis is planned.

Telecommunications

Five Block V Receiver tests were performed over DSS-14. The Block V Receiver successfully acquired and tracked the fully suppressed carrier signal, and flowed telemetry and Doppler data to JPL. Full Spectrum Recorder (FSR) tests were also performed over DSS-14 and -43. A detailed test result briefing is scheduled with the Project on December 20, 1994.

Anomaly Status

CDS Anomaly

On September 13, 1994, the Galileo spacecraft experienced its first computer memory cell failure in five years of interplanetary flight. This corresponds to one failed word out of about a half-million words in Galileo's aggregate computer memories.

During development of Galileo's advanced computer memory, it was recognized that perhaps dozens of cells would randomly fail over the eight-year mission lifetime. Engineers have been very surprised that no failures occurred earlier! To protect against such failures, special fault protection was included on board the spacecraft. Immediately upon detecting the failure on September 13, the fault-protection software executed as planned, stopping the ongoing sequence (which was playing back SL9 science data) and reconfiguring the spacecraft elements to a safe state.

Galileo engineers have isolated the exact location of the memory failure. In the near term, the Project will stop using 80 bytes of memory surrounding the one failed byte—a very small loss when compared to the almost 400,000-byte capacity of the spacecraft central computer. The sequence team has rewritten the background sequences, adjusting for lost time and working around the bad memory cell. Following verification and transmission of the "new" sequence, the spacecraft was back in full operation on September 25. Other than a small loss of some SL9 data, the memory failure should have no long-term effects on the Jupiter mission.

High-Gain Antenna

A special minisequence was transmitted August 26 to configure the spacecraft for the High-Gain Antenna (HGA) motor "hammer" activity on August 29. On that day, the HGA dual-drive motors were pulsed 1080 times in an attempt to free the stuck ribs. Prior to this activity, the motors were last pulsed in early 1993. Telemetry measurements indicate that the ribs are still stuck and there was no evidence of change in the antenna configuration. A routine Star Scanner checkout followed the hammering activity. There was no expectation that the HGA ribs would release, but this hammering was done as a final pre-Jupiter arrival check.

AC/DC Bus Imbalance

The AC/DC bus imbalance measurements have not exhibited significant change throughout this period.

Uplink Generation

The EJ-8 Final Sequence and Command Generation package was approved on October 10, 1994. The sequence covers spacecraft activities from October 17, 1994, to January 30, 1995, and includes the SL9 science data return, solar wind experiment, and Block V receiver and conjunction tests, as well as FSR and command conjunction tests.

The Project has approved the AACS 13.0 In-Flight Load (IFL) package for command generation. This IFL uses the time period from February 14 to 23, 1995.

Also approved was the Jupiter Orbit Encounter (JOE) Final Sequence and Command Generation package. This sequence covers spacecraft activities from December 3, 1995, to January 3, 1996, and includes windows for the Europa and Io encounters, Probe Relay, JOI, Probe symbol return, and Orbit Trim Maneuvers (OTMs) 1 and 2.

The Project also approved the JOCB Orbit Profile package. This orbit profile covers spacecraft activities from May 14 to June 29, 1996. The primary activity in JOCB is the playback of the arrival day science data (which includes the Io, Europa, and Torus observations). It also includes windows for OTMs 4 and 5, as well as real-time and playback collection of science data.

The Ganymede 1 (G1) Orbit Activity Plan was approved by the Project. This plan covers spacecraft activities from June 29 to September 1, 1996, and includes windows for OTMs 6, 7, 8, and 9, as well as a targeted encounter with G1 and completion of Jupiter Approach (JA)/JOE science playback data.

Ground Data System

As a result of a meeting held to review the status of parallel operations, the Mission Telemetry System (MTS) support of Galileo was fully decommitted effective August 19, six weeks before the target date established in 1993. MTS is the original system that supported Voyager, Ulysses, Magellan, and earlier projects. All future telemetry operations will use the more powerful, compact, and cost-effective Advanced Multimission Operations System/ Mission Ground Data System. ■

Meet The Team

If It's Critical or Innovative, Call the Engineering Office

If something is needed that is mission-critical or has never before been tried, chances are that the Galileo Engineering Office (EO) will be the people in charge. They are the ones responsible for completely reloading the inflight CDS software next February, something that has never been done before on any interplanetary spacecraft. They are in charge of the smooth release of the Probe for its journey into Jupiter's atmosphere and the first use of the 400-N engine to deflect the Orbiter's trajectory to Io, after which it will acquire Probe Relay data, not to mention Jupiter Orbit Insertion (JOI).

Of course, those are the out-of-the-ordinary requirements of the mission. The EO is also responsible for all the normal Trajectory Correction Maneuvers (TCMs) that have kept Galileo on its unique boomerang course through the solar system, real-time monitoring of spacecraft subsystems, nonreal-time analysis of telemetry data to verify and predict spacecraft performance, and all of the Testbed-based analysis of spacecraft systems using actual Galileo hardware (flight spares, engineering models, etc.) located here at JPL.

Team Structure

The Engineering Office, led by Ralph Reichert and deputy Gary Kunstmann, is one of four offices within Galileo Flight Operations. The office oversees the Probe Engineering Team led by Pat Melia, the Navigation Team led by Bill Kirhofer and Lou D'Amario, and the Orbiter Engineering Team led by Howard Marderness and his two deputies, Bob Gounley and Bob Barry.

The largest of these teams is the Orbiter Engineering Team (OET), 84 people who pay close attention to the health and safety of the Orbiter. They monitor overall spacecraft subsystems, including the spacecraft's main computer (Command and Data Subsystem or CDS), the attitude control system (AACS), the electrical power and propulsion subsystems, the thermal health of the spacecraft, and its telecommunications link with the ground. They also staff the Testbed, where there are exact copies of the CDS, AACS (including sensors, such as gyros and star scanners), tape recorder, and power simulator so that software can be thoroughly tested before sending it to the spacecraft. From time to time, Principal Investigators also bring in their science instruments to do testing. The OET also supports the real-time command process, as well as software development and analysis. (See related article in Issue 23, April 1990.)

Next in size is the Navigation Team, some 19 people who precisely design and control the spacecraft's flight path to achieve mission goals while using as little propellant as possible. (See related article in Issue 33, February 1994.)

Finally, there is the Probe Engineering Team, a dedicated group of 7 people from Ames Research Center and the Hughes Space and Communications Company, who built the Probe and are responsible for its health and safety. (Ames is the NASA center responsible for development of the Probe in support of the Galileo Project.) Some team members are stationed at the Laboratory: Marcie Smith, the Ames Probe Manager, and Charlie Sobeck are spending more time here as the Probe mission nears, and Pat

Galileo Relay/JOI Meeting. *At a recent Relay / JOI working group meeting, members discuss plans for the Relay / JOI critical sequence. Clockwise around the table beginning at front left are Pat Melia, Stuart Clark, David Acevedo, Vallerie Wagner, Ralph Reichert, David Allestad, and Tracy Neilson. Along the back wall are, from left, Gerry Snyder, Alicia Allbaugh, Eleanor Basilio, and presenter Bob Barry. (P44919B)*

Melia from Ames has been assigned to the Laboratory for many years. Their big effort begins next year, when the Probe goes through its final checkout and release and the Probe Relay data acquisition activities occur.

Important Accomplishments

Ralph looks back on the past five years since launch with a sense of accomplishment and amazement. "Galileo is probably the most complex and ambitious of any interplanetary mission," he says. "First, we had the encounter with Venus shortly after launch for the purpose of a gravity-assist and collecting science data, then the Earth and Moon, again for a gravity assist and to collect science data, then a first-time encounter with an asteroid (Gaspra), then Earth again, then another asteroid encounter at Ida, where we discovered a moon, then the unexpected challenge of Comet Shoemaker–Levy 9 came out of the blue, plus all the TCMs to get on the path to Jupiter and to support each of the encounters."

"Some missions are a single flyby of a planet," he notes. "So this is an amazing number of events to deal with and a major accomplishment for the whole flight team."

Other unexpected challenges the OET has helped resolve include the problem with the High-Gain Antenna and multiple CDS bus resets. "Each time a bus reset happens, we have to bring up the down string, reinitialize the spacecraft (e.g., turn the instruments back on), regenerate the onboard software sequence, and retransmit it back to the spacecraft."

Future Challenges

Besides the many one-of-a-kind events surrounding release of the

— see page 10

Survey Yields Encouraging Results

Our thanks to all of the readers who took the time to fill out and return the survey published in the last issue of *The Galileo Messenger*. About 2 percent of you returned the survey, which make these results statistically relevant. It was especially nice to receive comments from readers all over the world.

The survey indicates that 85 percent of you read the entire newsletter, while the rest (15 percent) scan the headlines and read selected articles. Virtually no one told us that they only scanned the newsletter or didn't read it at all.

We learned that many of our readers are scientists and engineers (35 percent), followed by educators (20 percent), administrative/management (10 percent), and students (7 percent). Thus, it is not too surprising that in-depth articles were the most popular, followed by simplified scientific explanations. Highly technical articles came in third, reflecting the large group of technical readers.

We were very pleased to learn that most of you save *The Messenger* (86 percent), many of you discuss it with your colleagues (72 percent), and almost half of you pass it on to others (49 percent). As far as our publication schedule, the most popular choices were to publish monthly (35 percent) or "as events dictate" (31 percent).

So far, about half of our readers are able to access *The Messenger* over the Internet, but many more of you expressed an interest in adding that capability in the future. For those who currently have this capability, you will be interested to know that we are in the process of putting some of the articles from past issues of *The Messenger* on line, as well. When this job is complete, we will have an index of articles by subject matter, as well as hypertext links that allow you to instantly "click" to related articles. All of this information will eventually be available on the Galileo Home Page on the World Wide Web. ■

Galileo Home Page Now On Line

In late November, the Galileo Project acquired its own Home Page at the Jet Propulsion Laboratory on the World Wide Web. The Galileo Home Page allows the Project to have all of its publicly available documents in one place for easy browsing. Here, you will find the current issue of *The Messenger* and articles from past issues, as well as press releases and other items of interest.

To access the Galileo Home page, type in the following URL:

http://www.jpl.nasa.gov/galileo

MEET THE TEAM from page 9

Probe and arrival at Jupiter, Ralph is well aware that the pace for his team will soon go into double time. Once in orbit around Jupiter, the spacecraft will require three Orbit Trim Maneuvers (OTMs) every orbit for 10 close encounters with Jupiter's satellites. That's about 30 OTMs over a 2-year period, compared to the 22 TCMs required during the previous 5 years.

Other major challenges are system testing the Phase 2 flight software for planetary operations and reloading the CDS flight software after JOI.

As Ralph looks to the future, he knows he can count on his team. "It's really been a pleasure working with some extremely talented and dedicated people on this project. Our teamwork is great because people are motivated to do the best job they can and collect the most science, while keeping the spacecraft safe. EO work may be stressful at times, but it's never boring because we deal with so many diverse subjects."

More About the EO Managers

Ralph Reichert is a California native, born in San Francisco. He graduated from UCLA in 1967 with a B.S. and M.S. in Engineering, and soon after came to JPL. Over the past 25 years at the Laboratory, he has worked primarily on flight projects—beginning in mission analysis and operations on Mariner '71, and continuing through the Viking, Voyager, and Galileo missions. Prior to launch, Ralph was the leader of Galileo's Mission Operations System Design Team and the uplink process design lead. He and his wife, Kako, have a 16-year-old son who plays on the Arcadia High School Varsity Football Team, so they attend all the AHS and UCLA football games. He also enjoys power boating and snow skiing.

Gary Kunstmann, EO deputy manager, has been at the Laboratory for over 32 years. His background is in the engineering and management of systems, ranging from unmanned spacecraft to tactical intelligence fusion systems. Past assignments include managing systems engineering for the All Source Analysis System and being assistant manager of the SDIO Pathfinder Project. He also managed an Air Force autonomous spacecraft program, the software system for Ulysses, and participated in the development of command subsystems for Ranger, Mariner, Viking, Voyager, Galileo, and Magellan.

Gary earned B.S degrees in Electrical Engineering and Math from California Polytechnic University in Pomona and an M.E. in Engineering Management from UCLA. He is an avid bicyclist and often commutes to JPL by bicycle. ■

Q & A

With this issue, we begin answering readers' questions about the Galileo mission. We received quite a few in last month's readers' survey and others over the Internet. We will try to answer at least one question in each issue.

Q Are there any plans to observe Jupiter's minor satellites? If so, what type?

A The Imaging Team has developed a comprehensive plan for observing Jupiter's four small *inner* satellites—Amalthea, Thebe, Adrastea, and Metis. The plan involves imaging each satellite at each of nine geometries. These geometries consist of three illumination conditions at each of three longitudes spaced approximately 120 degrees apart. The illumination conditions are:

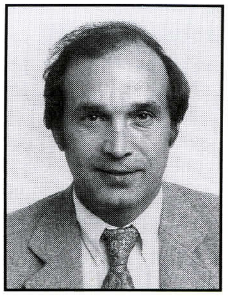
- Low solar phase angle (Sun–satellite–spacecraft angle <20 degrees)
- Moderate solar phase angle (40–65 degrees) with the Sun from the east
- Moderate solar phase angle with the Sun from the west

These nine geometries will allow us to study the size, shape, spin state, colors, and photometric properties of these small satellites, as well as ephemeris improvements for Adrastea and Metis and improved understanding of surface morphology on Amalthea and Thebe. The low-phase observations are accomplished using four-color on-chip mosaics recorded with SSI internal camera data compression; the moderate-phase observations are done in a single color and will be windowed and compressed by the spacecraft computer. Most of the low-phase observations are scheduled for Galileo's ninth orbit around Jupiter, when there is ample downlink capability. Use of on-chip mosaicking requires that the range from Jupiter be >10.8 R_J (Jupiter radii) to keep radiation noise acceptably small. Resolutions are typically 5–10 km/pixel providing 3 to 40 pixels across the bodies, depending on the observation and the target body.

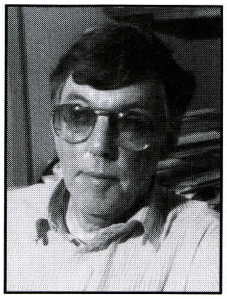
Because the ranges to the *outer* small satellites from Galileo are so large, ground-based observations are just as good with much higher power telescopes.

Ken Klaasen
SSI Science Coordinator

Gaspra Regions Named After JPL Galileo Scientists


Dr. Clayne Yeates

Two former JPL scientists on the Galileo Project have been honored by having regions on the asteroid Gaspra named after them. Yeates Regio honors the late Dr. Clayne Yeates, who was Galileo science manager from Project inception and science and mission design manager at his death in 1991. Dunne Regio was named in honor of the late Dr. James Dunne, who served Galileo for over a decade and followed Yeates as science and mission design manager until his death in late 1992. Both contributed greatly to Galileo's successful encounter with Gaspra in October 1991 and to the Project in general. A third region was named for G. Neujmin, the Ukrainian astronomer who discovered the asteroid in 1916. The International Astronomical Union (IAU) recently approved these names, as well as new designations for various craters on Gaspra, named after resorts and spas around the world. This follows from the fact that Gaspra was named for a resort on the Crimean Peninsula. Recently named craters include Calistoga (top near the day–night terminator) for a resort in California, Baden–Baden (center), and Yalta (far side, not visible), after a Ukrainian resort.


Dr. James Dunne

PROJECT MANAGER from page 1

ries and the Attitude and Articulation Control Subsystem (AACS) spare memory before loading new Flight Software (FSW) in these memories early next year. Every cell was found functional. Ironically, just weeks later on September 13, a cell failure caused the data return sequence to be aborted; it took two weeks to fully diagnose what had happened and resume playback. It is encouraging that this is the first Galileo memory cell failure; the prelaunch prediction was that quite a number of cells would have failed by now and, accordingly, we have always had workarounds in our plans. Now, based upon the flight experience of Galileo and Magellan, we should see no more than a few cells fail, which should be quite tractable.

We are delighted that NASA and Australia's Commonwealth Scientific Industrial Research Organization (CSIRO) are now proceeding to modify the Parkes 64-m Radio Astronomy Antenna in Australia in order to include it in the DSN/Galileo S-band antenna array for the orbital tour data return. Parkes will improve our data return by nearly 20 percent for the orbits that most need improvement and will contribute very substantially to the overall mission, just as it did for Voyager.

Calendar year 1995 is the crucial year for Galileo. Beginning in February and through mid-March, we will be uplinking the new FSW that provides backup capture of Probe data in the CDS and vital new autonomous fault-protection algorithms. The final checkout of the Probe will be performed next using the new software to buffer and return checkout data.

The Probe Release is scheduled for July 13 following a week of painstaking operations. Final prerelease Trajectory Correction Maneuvers (TCMs) for refining the Probe trajectory will be April 12 and June 23, 1995.

On July 20, the Galileo Orbiter 400-N main rocket engine will be used for the first time to perform the Orbiter Deflection Maneuver (ODM) that aims the Orbiter to its required Io flyby point, which properly establishes the Orbiter's trajectory for Relay and the Jupiter Orbit Insertion (JOI) maneuver.

In 1995, virtually all *spacecraft* activity will involve preparations for Jupiter arrival. And the large majority of arrival preparation effort on the ground will be in preparing for contingencies. If we could count on everything going as planned, we would be nearly ready right now. The big job is to determine what problems to prepare for and program the spacecraft to detect and correct such problems or, if time permits, safe itself and wait for corrective commands from the ground.

When performing the Probe Relay and Jupiter Orbit Insertion, all fault protection must be autonomous since each of these events occurs in less than the nearly 2-hour round-trip light time making ground interaction out of the question without even considering think-time and commanding reliability. Our goal is to require no ground commanding during the last 21 days before arrival except for TCMs and setting the command loss timer. Throughout the life of the Project, arrival contingency planning has been a continuing process. Now in the home stretch, with five years of flight experience and some new insights to potential vulnerabilities, we will be doing everything we reasonably can to maximize the reliability of Relay and JOI.

In parallel with our arrival preparations, work on the orbital mission will continue in full swing. The new Orbital Phase FSW must be completed and thoroughly tested and detailed orbital sequences for many of the orbits generated. We are currently facing a substantial schedule challenge to be ready for the first orbital tour satellite encounter—Ganymede 1 (G1)—on July 4, 1996. Our Spacecraft System Testbed planning is being streamlined and the planning staff increased to ensure our G1 readiness.

Happy holidays to the friends of Galileo everywhere and let us all look forward to 1995 culminating in the successful arrival of Galileo at Jupiter!!! ■

— Bill O'Neil
Project Manager

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The Galileo Messenger

Issue 36 **May 1995**

From the Project Manager

The Galileo spacecraft is performing flawlessly and the Project Team is vigorously working the broad spectrum of activities required for the Jupiter mission. It is most heartening to see all these efforts moving so briskly through the multitude of diverse problems and contingencies. The Team clearly has the knowledge, skills, and dedication to safely deliver Galileo to Jupiter and perform the Jupiter mission. We are doing extensive fault protection and contingency planning—we will be well prepared to properly respond to contingencies.

Some very significant milestones were achieved over the past five months. We completed the SL9 data return as planned in January. In February, the new flight software for Jupiter arrival (Phase 1) was uplinked to the Command and Data Subsystem (CDS) and the Attitude and Articulation Control Subsystem (AACS). This marked the first time a planetary spacecraft central computer was completely reloaded in flight. Because of the great complexity and criticality of this process, we allocated six weeks for it. We were surprised and elated when the whole thing was done without a significant problem within one day of the *nominal* 25-day schedule.

Also in February, the Probe ground battery testing executed

—see page 12

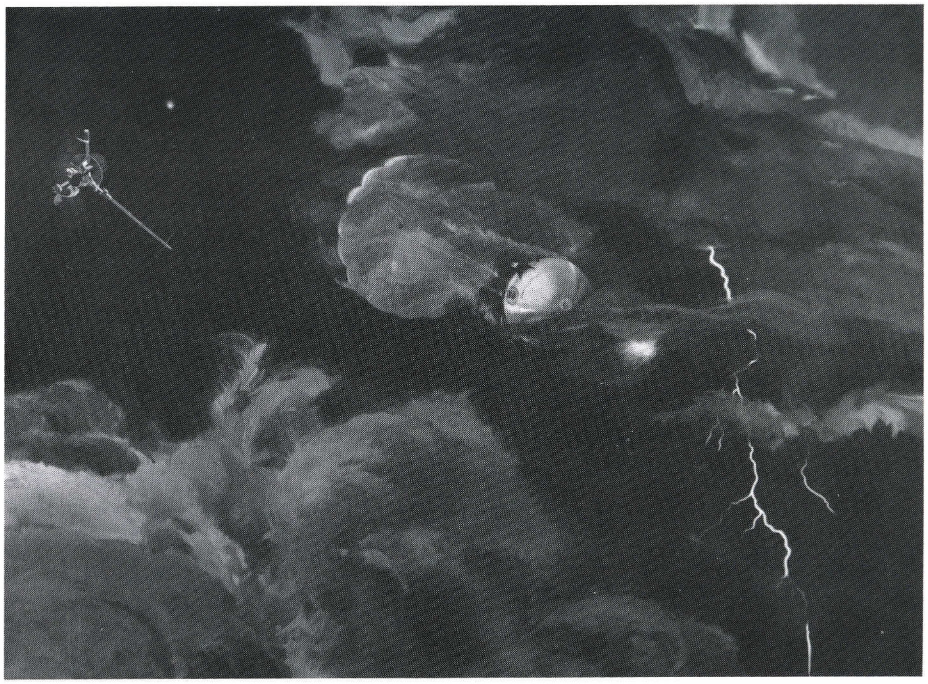
Ready to Go—The Probe Checkout Results

Yes! The Galileo Atmospheric Probe systems are functioning as designed. An exuberant Marcie Smith, Galileo Probe Manager at Ames Research Center (ARC), has announced that the checkout on March 16 confirmed a healthy Probe, ready for its July release and solo flight for December arrival at Jupiter (see story, p 3). What did the Probe Engineering Team (PET) under the direction of Chief Pat Melia test, and how did they do it?

Verifying the New Flight Software

Using the newly loaded flight software (see story, p 6) for the first time, the team verified that Probe data—telemetry in symbol form—could be stored in the spacecraft central computer's spare memory and recovered with a memory readout (MRO). The data compression feature of the new flight software and the direct use of Command and Data Sub-

—see page 2



Arrival day, December 7. The Probe parachutes through the swirling clouds over Jupiter while relaying science data to the Orbiter.

system (CDS) memory (bypassing the tape recording process) provided good data quickly—within a day. Processing of the same data by the usual method, a Low-Rate Probe Record (LPR) format (also a new flight software capability) recording on tape that is then downlinked to Earth, verified use of the new method.

Will the Battery Last?

The Probe will be powered by a three-module lithium battery during its solo flight and descent to Jupiter. Tests of the open circuit voltage (OCV) indicate it is holding at 39 V, even at its advanced age of more than 6 years. But how do you test battery capacity and avoid using precious energy intended for the Probe task? Only power from the Orbiter can be used for testing. So the PET planned ahead. Three identical battery sets kept under simulated flight conditions were made available here on Earth. One battery set began a 155-day "coast" to be followed by a simulation of the experiments that the actual Probe will conduct on arrival at Jupiter. By beginning the activity before the actual Probe release in July, the PET will be able to address any anomalies that occur, just as you would prepare for a big event with a dress rehearsal or dry run presentation. A Flight Descent Antecedent Test (FDAT) confirmed that all is well. The other two sets will be used for anomaly response, if required. Ralph Reichert, Engineering Office Manager, said that ground testing indicated the batteries showed substantial margins in all areas.

What Other Functions Were Tested?

A test of the accelerometers in the Atmospheric Structure Instrument (ASI) checked out fine. The Neutral Mass Spectrometer (NMS) ion pump removed excess argon gas, relieving the ionization chamber of that burden. The radio relay hardware (RRH) aboard the Orbiter was also exercised during this activity; it received the Probe's signal and passed it on to the CDS. The RRH did its job very well.

Are we surprised at these positive results? After launch of Galileo in October 1989 and again in December 1990, the Probe had successfully passed a System Functional Test (SFT), indicating all science instruments and engineering subsystems were functioning well. In November 1992, a full Mission Sequence Test (MST) reassured us that each unit received and executed the stored sequence commands as planned during the actual pre-entry and descent mission (except for irreversible events, for example, staging). The Abbreviated SFT (ASFT) conducted in December 1992 on Earth-2 approach focused on the battery set check and removal of argon from the NMS ionization chamber. The results were excellent, just as with the current testing.

Nevertheless, on April 18, Project Galileo Manager William J. O'Neil met at Ames Research Center with Probe Scientist Rich Young and the Probe Science Team; Probe Manager Marcie Smith and Deputy Probe Manager Charlie Sobeck (ARC); and Chief Pat Melia and the Probe Engineering Team, including the Hughes team led by Program Manager Bernie Dagarin. The teams made a careful evaluation of the checkout results. They studied the FDAT performance and the subsystem functionality shown in the ASFT to determine whether to follow their nominal plan or the alternative contingency mission. The contingency mission would have omitted the pre-entry science, that is, data on Jupiter's atmosphere for areas not to be reached by the Orbiter. Switches which detect deceleration would have deployed the parachute for descent so that available energy would be used primarily for the collection and relay of descent phase science data. As we go to press, the Project Manager has approved a full Probe mission. ■

Galileo Educational Outreach

"America's future demands investment in our people, institutions, and ideas. Science is an essential part of that investment. . . ." So states the Clinton administration's policy statement, "Science in the National Interest." NASA has accepted the responsibility to contribute to this figurative "call to arms" and has challenged its Centers and its individual projects to develop programs which use the thrill of discovery to better capture the imagination of our elementary and secondary school students and teachers.

Called "educational outreach," these programs involve the development of various products which are designed to help make existing math and science curricula more exciting and relevant. Galileo is very actively contributing to this endeavor in several ways. Some of those activities underway or completed are displays at the National Science Teacher Association Conference, curriculum modules, support to the NASA-sponsored Minority Astronomy Program, an Educator's Slide Set, and an Arrival Day poster. Some of the planned activities include "Live From Jupiter," an on-line interactive view into mission operations (starting in late summer and continuing through December 1995), teacher in-service workshops, and regular mission commentaries during the tour with special attention to teacher and student needs. Stay tuned! ■

On My Own—At Last!
The Galileo Atmospheric Probe Release

Probe Release. How sweet that sounds. Ever since the October of '89 launch from Space Shuttle Atlantis, I've been aboard the Galileo spacecraft, a journey of over 3.7 billion kilometers (2.3 billion miles). And now my solo experience is about to begin. Chief Pat Melia and his Probe Engineering Team (dedicated to my health and career) have checked me out thoroughly, all 338.9 kg (see p 1). I'm ready for those Earthlings to proceed with my release.

Everything is planned. The Probe Release Sequence Timeline shows the important milestones. On July 5, I will be powered up so I can send data to PET via the new Command and Data Subsystem software; the data will also be tape recorded, just in case. Then on July 11, after they're sure I'm working fine, my umbilical cable, my only communication path to the Orbiter, will be cut. No more instructions from Galileo. I'll be on my own, going ballistic.

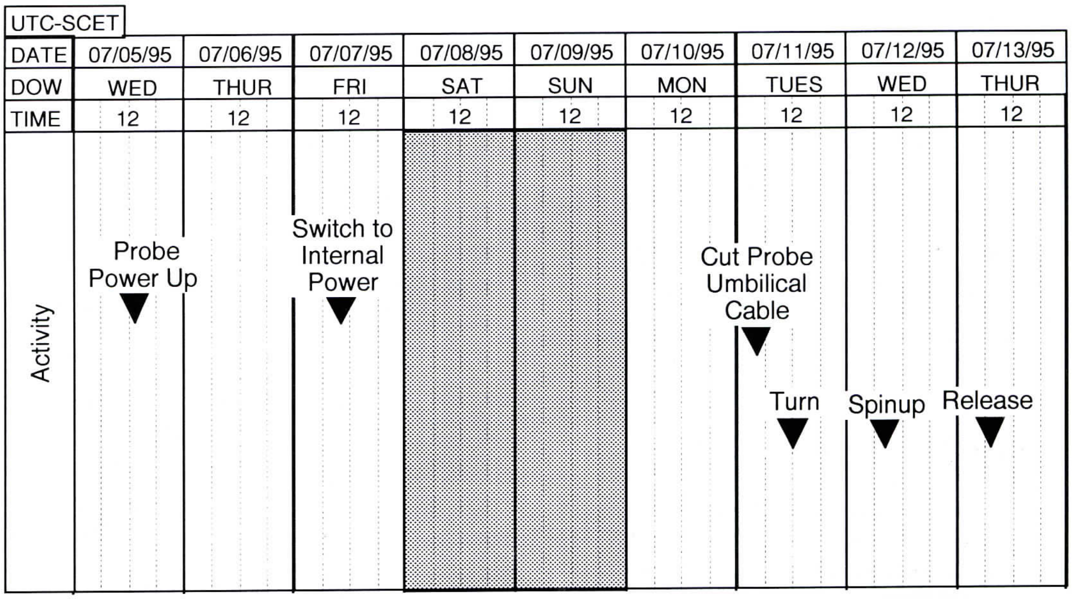
Of course, it is very important that the Orbiter target me to the right trajectory. To do this, the Orbiter will establish my entry Flight Path Angle (FPA), the angle between the direction I'm headed and the local horizontal (as measured in Jupiter's atmosphere). Two Trajectory Correction Maneuvers (TCMs 23 and 24) will nudge the Orbiter just enough so that the separation push and all other forces (such as gravity) will place me on a slightly descending FPA of –8.6 deg (±1.4 deg) at 450 km altitude above the oblate Jupiter (the planet is flattened at both poles)—the "sea level" at Jupiter being at 1-bar or about one Earth atmosphere.

On July 13, with an action something like the ascent of a child's toy helicopter, the Orbiter will carefully turn to the appropriate attitude for Release, switch from dual-spin to all-spin mode and spin up to 10.5 rpm, and let go! At the "let go" command, the three separation nuts will explode and separation springs will give me a gentle 0.3 m/s push to begin my 5-month coast to Jupiter. My attitude at Release, about 10 deg from Earthline, will be parallel to the atmosphere relative entry velocity or zero angle of attack (±6 deg) at the point during my entry phase when I am experiencing maximum heating. I want to go in heat shield first so it will protect my instruments from a head-on encounter with the atmosphere.

At key points throughout, the sequence of commands to the Orbiter will stop, waiting for "go commands" to be received from Earth. You can imagine that I am depending heavily on the Flight Team to perform these steps with great care and accuracy.

On December 7, the coast timer will start the action 6 hours prior to entry. After entering the upper atmosphere, slowing down, removing my heat shield, and deploying my parachute, my science instruments will collect data on Jupiter's atmosphere. Weather permitting (heat, rain, snow, and air pressure), I'll relay the data to the Orbiter via radio before my batteries wear out. They'll only last about 75 minutes or so. It will be the end for me, but what a thrill to say, "I fulfilled my mission!" ■

—The Probe



The Probe Release Sequence Timeline.

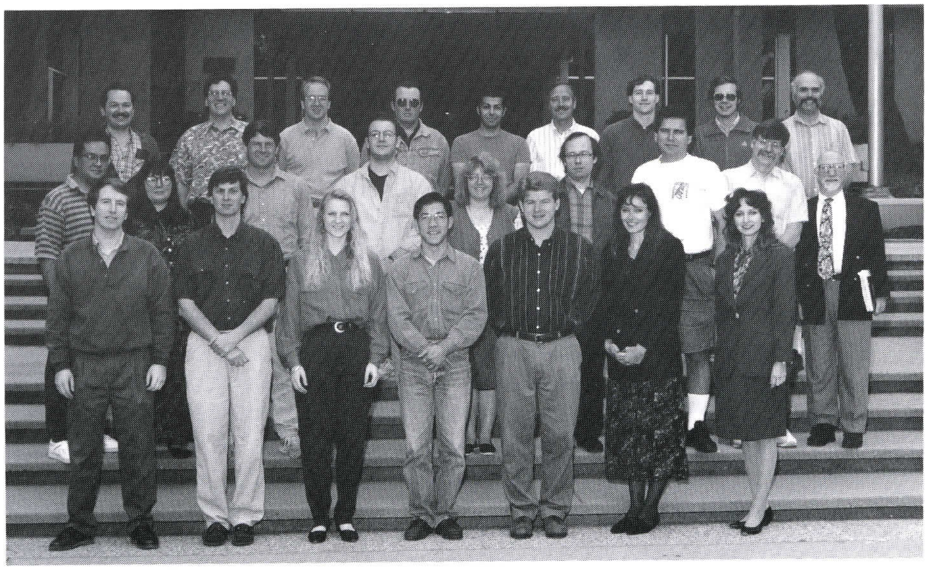
Meet the Remote Sensing Science Group

Five Orbiter Instruments Depend on Them

The Remote Sensing Science Group (RSSG) is the hub of activity for the four remote sensing science instruments mounted on Galileo's scan platform: the Solid-State Imaging (SSI) Subsystem, the Near-Infrared Mapping Spectrometer (NIMS), the Photopolarimeter/ Radiometer (PPR), and the Ultraviolet Spectrometer (UVS), plus a fifth instrument, the Extreme Ultraviolet (EUV) Spectrometer mounted on the spinning part of the Orbiter. The RSSG has the responsibility to acquire the wealth of remote sensing science data available at Jupiter and its moons. To this end, the teams responsible for these instruments have been united with the necessary support services under the leadership of Brian Paczkowski as the Remote Sensing Science Group.

The challenge is twofold. Success depends on careful selection in collecting essential science data and integration of the commands to each instrument so that data can be downlinked through a single pipeline. Initially, science teams select the type of information they anticipate will reveal the history of the Jovian system and its present composition and processes. Science coordinators on the instrument teams respond by developing specific design sequences (series of commands) that activate the instruments and the spacecraft's scan platform to perform observations; collect, process, and record the desired data; and return it to Earth. They then optimize the balance of collection versus downlink capabilities for the design of each and every satellite encounter and cruise sequence.

There are four science teams. The SSI Team (Ken Klaasen, Team Chief, and Science Coordinators Herb Breneman, Catherine Heffernan, Todd Jones, Jim Kaufman, and Dave Senske), develops the imaging sequences for science data to be gleaned from the camera that brought you those impressive pictures of comet Shoemaker–Levy 9 crashing into Jupiter. The NIMS Team Chief, Bill Smythe, and Science Coordinators Kevin Baines, Elias Barbinis, Paul Herrera, John Hui, Rosaly Lopes-Gautier, Frank Leader, Adriana Ocampo, and Marcia Segura will focus on a study of the Jovian atmosphere to learn the composition and thermal profile for emissions in the 0.7- to 5.2-μm spectral range and from 180 to 340 K. Joe Ajello, UVS/EUV Chief, and his team, Science Coordinators Steve Edberg, Lonnie Lane, Keith Naviaux, and Kent Tobiska, develop sequences to study the physical processes in the upper atmosphere of Jupiter, the Io plasma torus, and the composition and thermal structure of volatile gases escaping from Jupiter's moons. Terry Martin, Science Coordinator for the PPR Subassembly, and his assistants, Ian Claypool and Leslie Tamppari, develop the sequences needed to collect thermal and reflected radiation data about satellite surfaces and atmospheric properties.



The Remote Sensing Science Group: (top row, from left) Elias Barbinis, Brian Paczkowski, Keith Naviaux, Ian Claypool, Barkev Azadian, Kent Tobiska, Brad Cracchiola, Dave Bliss, and Steve Edberg; (middle row, from left) David Acevedo, Marcia Segura, Todd Jones, Jerod Gross, Laura Barnard, Herb Breneman, Frank Leader, Bill Smythe, and Lonnie Lane; (bottom row, from left) Jim Kaufman, Dave Senske, Leslie Tamppari, John Hui, Lisa Crowell, and Rosaly Lopes-Gautier. (Not pictured: Joe Ajello, Kevin Baines, Jeff Culwell, Bill Cunningham, Fred Gangloff, Catherine Heffernan, Paul Herrera, Ken Klaasen, Paul Koskela, Terry Martin, Keith Meredith, Adriana Ocampo, and Laura Su.)

The RSSG has responsibility for the development, maintenance, and operations for the key software program set used by the instruments. Fred Gangloff, Paul Koskela, and Laura Su comprise the Development Staff for POINTER (Planetary Observation Instrument Targeting and Encounter Reconnaissance), the software tool for the SSI, NIMS, PPR, and UVS instruments. Brad Cracchiola, Lisa Crowell, Jeff Culwell, and Jerod Gross are the four Remote Sensing Design Engineers (RSDEs) who employ POINTER to develop observation designs, define the scan platform patterns (or mosaics) required to acquire the science objective, and generate the detailed commands to the platform to perform the observations. Engi-

neers Bill Cunningham and Keith Meredith for the SSI Team and General Science Instrument Analyst David Acevedo for the other teams are on hand to monitor and care for the health and safety of the remote sensing science instruments. Then, RSSG Integrator Dave Bliss blends the sequences so that the product is internally consistent and conflict free. The result flows to the Sequence Team, where it is folded into the overall sequence. The RSSG Integrator also receives the Fields and Particles Science Group (FPSG) recorded observation requests and inserts them into the overall record plan. In turn, the FPSG integrates requests from RSSG for real-time science observations (by NIMS and UVS/EUV) into the overall real-time science collection plan. Laura Barnard, assisted by Barkev Azadian, provides secretarial support for all the RSSG tasks.

Currently, sequences for the Jupiter Tour orbits are being prepared, reviewed, checked, and validated. After each Encounter, Brian Paczkowski as Lead will oversee the ongoing activity of fine-tuning the uplink commands and orchestrate team requests for revising the data playback scenarios to ensure that each instrument can contribute the best data within the available downlink telemetry.

The uplink development schedule for the orbital tour is very demanding. For the RSSG, 10 weeks are needed to go from the initial high-level plan for the entire orbit (encounter and cruise) to the detailed commanding level. Another 8 weeks are used to refine the commands for the encounter sequence only and prepare a sequence load that can be executed by the spacecraft. Also during these 8 weeks, development of the next orbit begins so that two sequences are developed in parallel. Brian commented, "The performance of the instrument teams and the rest of the RSSG staff has been exceptional in meeting these schedule demands."

Brian Paczkowski, RSSG Lead

It was the time of the Apollo Missions when, through his own telescope, young Brian studied the sky over Scranton, Pennsylvania and considered traveling the star highways in person. His reality today is space exploration by remote control as Lead for the RSSG. After earning a BS in astronomy at Villanova University and performing graduate work at Ohio University, he came directly to JPL in 1983. Working under Ken Klaasen, he developed the imaging sequence for Galileo's first flyby of the Earth. Seasoned by stints with CRAF, Cassini, and as Deputy Team Chief for the Galileo Science Requirements and Operations Planning (SROP), Brian moved into leadership of the RSSG when the Project reorganized. To learn how Brian brings balance to his highly technical lifestyle at JPL, visit his office and catch a glimpse of the Paczkowski family slide show, featuring 18-month-old daughter Kira and wife Sharon (yes, computer images, sharp and colorful). In addition to family activities, Brian enjoys working with wood to create art objects, designing and building wooden furniture, playing a round of golf, and remembering Earth-bound travel to faraway Hawaii and Bora Bora. At work at JPL, he is looking to the exciting adventure coming so soon. Encounter Day on December 7 is clearly visible, but much planning, checking, and rechecking is still to be done to ensure our successful mission. ■

In Memory of John E. Zipse

Dr. John E. Zipse, a much respected member of the Galileo family, died of a heart arrhythmia on February 8 at age 47. He was the Galileo Flight System Development Office Manager for the Galileo Project and the Manager of the High Speed Spacecraft Simulation (FASTSIM) Task for JPL. In the former position, he managed the development of the new Galileo spacecraft software for CDS, AACS, and the SSI subsystems. In the latter position, he led a team to implement bit-level high-speed spacecraft simulations of the Galileo and Cassini spacecraft to support software development and command sequence verification. In 1991, he received the NASA Exceptional Service Medal.

At the time of John's death, the Project was reloading Galileo's entire AACS and CDS operating systems (see story, p 6). We owe some of our success in achieving this reload to John's leadership during its development. His foresight and leadership in developing the FASTSIM high-speed simulator for Galileo contributed to the rapid development of the software to be reloaded onto the spacecraft in March 1996.

In 1970, John graduated from the Massachusetts Institute of Technology with a BA degree in applied mathematics and an MA in theoretical nuclear physics; he received the doctorate degree in experimental high energy physics from the University of California at Berkeley for work done at the Stanford Linear Accelerator Center. In 1976, the project he collaborated on was recognized when its leader was awarded the Nobel Prize in Physics for the discovery of the charmed quark. At the NASA Johnson Space Center (1975–1977) and the Goddard Space Flight Center (1977–1979), he designed and built innovative software and hardware systems.

Posted on the Galileo Project Office bulletin board is this heartfelt tribute: "John's charity, zest for truth, search for peace, and dedication to fun will be greatly missed." ■

Reloading the Operating System on Galileo's PC

An operation unprecedented in the history of spacecraft flight operations was executed by Project Galileo in February of this year: the spacecraft's operating system was completely reprogrammed while in flight. The software transplant, Phase 1 of a two-part effort, was required to compensate for the failure of the high-gain antenna (HGA) to open, jeopardizing the accomplishment of many critical mission objectives.

Shortly after the April 1991 HGA deploy failure, Les Deutsch of the Tracking and Data Acquisition (TDA) Technology Office was tasked with looking for a way to perform the Galileo mission, using the low-gain antenna for communications. The conceptual applications of ongoing coding and compression research were explored quietly through the summer, leading to a short options study led by Deutsch in the fall—with stunning results. Next, Jim Marr, representing the Project, and Deutsch assembled a team of approximately 45 members who spent 2-1/2 months developing an alternate method of returning data from the 10-satellite orbital tour if the HGA could not be opened. After this concept (which will be implemented as Phase 2 in March 1996) was approved by NASA, a second study, with a team of 12 members led by Wayne Kohl of the Avionics Systems and Technology Division at JPL, was initiated in 1992 to determine how best to ensure the return of Probe data. Recommendations from that second study were successfully implemented by the just accomplished Phase 1 inflight load (IFL) of new software.

In March 1993, having exhausted all efforts to open the HGA and, in accordance with the agreements reached with NASA in April 1992, full-scale development of Phase 1 and Phase 2 flight and ground software began. Project Galileo formed a Systems Development Office led by Jim Marr, and TDA established a Galileo S-Band (GSB) development task led by Joe Statman. For Phase 1, two major subsystems were affected: the Command and Data Subsystem (CDS), which is Galileo's central computer, and the Attitude and Articulation Control System (AACS), which orients the spacecraft, points the scan platform, and controls the propulsion subsystem. The CDS and AACS teams began writing new flight software (FSW) for the two subsystems while the Ground Data System (GDS) team made supporting changes in the uplink command and downlink telemetry systems. In August 1994, the memory cells in the CDS that had not been in regular use were tested to verify their functionality, and the AACS's redundant (backup) memory was tested. Then the Orbiter Engineering Team (OET) made up command packages, with support from the Sequence Team, and tested them on the Galileo testbed. On January 30, the Phase 1 reprogramming was begun by the Galileo Mission Operations and Engineering (MO&E) team.

Loading the new software involved many risky challenges. To accomplish the reloading, Galileo's full redundancy had to be temporarily disabled, on multiple occasions. Additionally, safing routines had to be executed during the reload process. The CDS had been designed with two redundant halves, or "strings," each of which has a primary and an extended (backup) memory. The CDS normally operates from the primary memory on one string with the second string acting from its primary memory as an active backup. The AACS also has two redundant strings, but operates from one string, with the second string in a nonactive backup mode.

Taking advantage of this redundancy, the Phase 1 FSW for the CDS was loaded into the extended memory of both strings, while both strings used their primary memories to control the spacecraft. Redundancy was temporarily disabled and one string was configured to operate out of its newly loaded extended memory, while the primary memory was tested on that string, and then new software was copied into it. That string was then reconfigured to operate out of its primary memory again. This process was repeated for the second string, after which full redundancy was reestablished and normal operations continued with the new FSW. The AACS memory was then tested and reloaded, one string at a time, while the other string remained active. Although the rewritten AACS FSW was only a small percentage of the total code, a total recompile was necessary that required reloading all the code.

The new FSW compensates for the fact that without the HGA, Probe data cannot be transmitted back to Earth in real time. The Data Memory Subsystem (DMS) tape recorder was to have been used as a backup to the real-time link, but is now the primary method of data acquisition. The new FSW enables the CDS extended memory to be used for backup data storage through the primary Probe mission requirement of reaching 10 bars, or the first 39 minutes of the descent. Ensuring this redundancy was a key objective of the Phase 1 effort. In addition, because the tape recorder can only be connected to one CDS string at a time, the new FSW was written to autonomously switch the recorder to the

other string if the first string were to go down.

In the AACS, the new FSW solves several problems that emerged after launch. First, it provides new levels of fault protection for relay link antenna pointing. Because the star scanner may not be reliable in Jupiter's intense radiation field, the new FSW provides new backup methods of roll (clock) reference. Each backup method is more robust than the previous method, although somewhat less accurate. However, each method provides adequate roll control, and project designers are confident that critical mission events will be accomplished.

In March 1995, the new Phase 1 FSW successfully carried out its first task onboard the spacecraft—checking out the Probe.

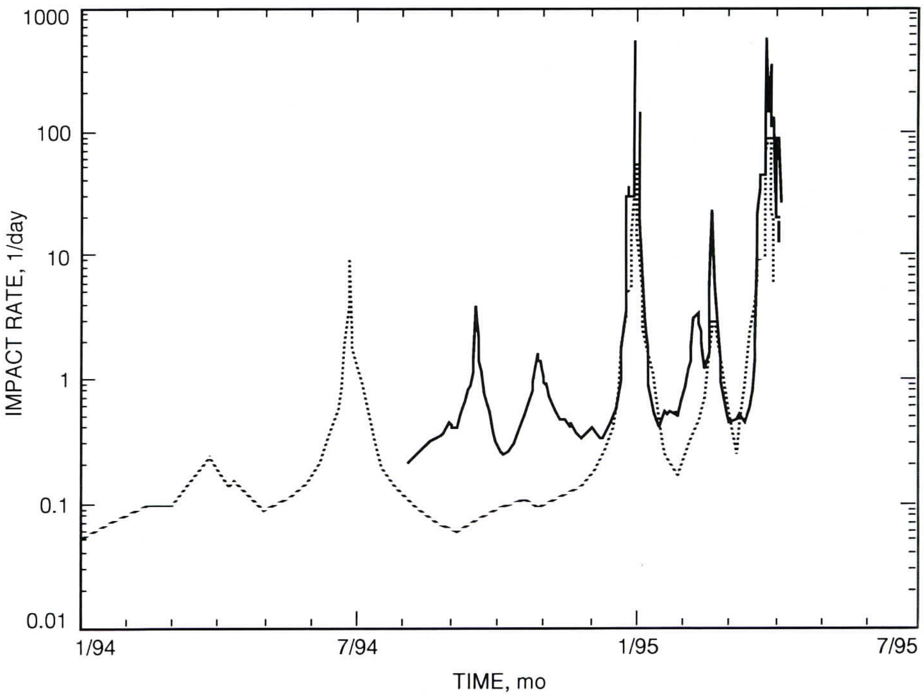
Having achieved the goals of Phase 1, Systems Development team members are now in the home stretch of Phase 2, in which vastly more extensive changes will be made to CDS FSW and to the ground system software and hardware, plus changes to AACS FSW and that of 8 of the 11 science instruments. These changes, due to be sent to the spacecraft in March 1996, will carry the Galileo mission through to its completion in December 1997. ■

— Irene Struthers

Dust Streams From Jupiter—Our First In Situ Measurements of Jupiter's Environment!

In February, Eberhard Grün, Principal Investigator for the Dust Science Team, discussed their findings and analyses of dust stream emissions from the Jovian system in a noon-time presentation at JPL. Eleven of these periodic, narrow, collimated (in parallel paths) streams of dust particles, unlike any ever seen before, were detected by Ulysses in 1992. Since June 1994, seven streams have been seen by Galileo—starting at about the same distance (2 AU or about 300 million km) from Jupiter as Ulysses was when it first detected them. Carol Polanskey, Team Chief for the Dust Detector Subsystem (DDS), reports that the streams are getting more intense and lasting longer. (In July 1994, a reprogram of the Galileo DDS, enabled by analyses of data from the Ulysses dust detection experiment, fortuitously improved the DDS identification of particles in time to observe these intriguing streams.) The rate of events, as shown in the figure, escalated from less than one to nearly 1000 per day by the end of 1994. The most recent stream contained more than 2000 particles and continued for more than 3 weeks.

Dust in space? We're familiar with the dust particles suspended in Earth's atmosphere. Dust particles scatter light from the Sun, often producing a red-orange glow at sunset. To see interplanetary dust as Cassini saw it 300 years ago, Grün said that we must travel to places like Hawaii



The rate of dust events plotted over a period of two years, showing the initiation of streams in June 1994. Instrument reprogramming, using data from the Ulysses dust experiment to optimize the particle collection of Galileo's DDS, took place one month later—just in time to catch the surprising dust events that continue to this day. (The dotted line shows only the dust events that would have been detected if the instrument had not been reprogrammed to detect the small particle streams initially discovered by Ulysses. The solid line shows all the events detected since reprogramming in July 1994.)

where there are very dark skies and low pollution levels. About one-half hour after the Sun goes down, one can look west, line up the Moon and Venus to establish the ecliptic plane, and observe the inverted cone-shaped "cloud" caused by sunlit interplanetary dust. Scientists believe that these particles are emitted under gas pressure from comets. Further away from the Sun, dust particles thought to be the result of collisions of asteroids and meteoroids have been detected by the Infrared Astronomy Satellite (IRAS). Since all bodies absorb heat from the Sun, these grains of dust can be viewed in the infrared (heat) portion of the electromagnetic spectrum. Interstellar (star) dust pervades the entire universe.

How do we know about dust in the outer solar system? The story is told by tiny particles, smaller than interplanetary dust, that are hitting the Dust Detector Subsystem (DDS) onboard Galileo. Particles passing through the sensitive area of the DDS (0.1 m^2, about the size of a large colander), are ionized when they strike the back of the instrument. Polanskey explained that the speed of a dust particle can be determined from the difference between the pulse from collected ions and the pulse from collected electrons. The typical impact speed is 20 km/s (12.4 mi/s), a speed which would take the particle across the U.S. in about 3 minutes. Mass and charge can also be calculated. The particles, averaging 10^{-14} g, are typically $\leq$0.1 µm in radius—about one-tenth the size of the airborne dust particles seen when the Sun shines through your window at home. Direction can be found from the known time and orientation of the spinning spacecraft. The dust is affected by solar radiation pressure, solar gravity, and electromagnetic forces. Solar ultraviolet waves cause particles to be charged up to 5 volts. The spacecraft's extended journey to Jupiter permitted the dust collection studies to cover the range of 0.7 to 5 AU (about 1 million to 7.5 million km).

Why are dust particles being ejected from the Jovian system in streams of increasing intensity and over a longer span of time? Scientists are looking to Galileo to supply them with the data to answer this question. They theorize that small dust particles (<20 µm) are electromagnetically accelerated by Jupiter's magnetic field; those smaller than a few micrometers are accelerated to greater than escape velocity from Jupiter. (In fact, those streams are fast enough to be leaving the solar system!) But what is the source of this dust? The periodicity of the dust streams indicates a single source. According to one model, it is Io's volcanic activity; another model takes the position that the dust particles originate in Jupiter's gossamer ring. In 1994, members of the Dust Science Team considered the possibility of submicrometer-sized dust being produced by the impact of comet Shoemaker–Levy 9 on the gossamer ring particles, tidal disruption, or from the impact on Jupiter itself.

Armed with data gathered while Galileo is in orbit around Jupiter, scientists expect to find answers to the mystery of these surprising dust emissions. Presently, they are relying on the pattern of periodicity to predict that this June, after a smaller burst in May, Galileo's dust detector will be bombarded with the most intense stream ever, twice the size of the current stream, and will last for the longest period. Galileo will be 0.6 AU (about 0.9 million km) away from Jupiter at that time. We must wait and see. It won't be long now. ■

Up To Date

The following activity occurred over the last four months (November 25, 1994, to April 7, 1995).

CDS and AACS Inflight Loads

The Command and Data Subsystem (CDS) 9.5 software inflight load (IFL) and the Attitude and Articulation Control Subsystem (AACS) 13.1 software IFL completed nominally on February 12, 1995, and February 24, 1995, respectively (see story, p 6).

SL9 Observations/ Data Return

The Shoemaker–Levy 9 (SL9) science data return was completed on January 29, 1995 (see story, p 10). Overall, 98.84 percent of the SL9 science data transmitted by the spacecraft were successfully received and processed through the ground data system during the 1994–95 SL9 data playback campaign.

Solar Wind Scintillation Experiment

The solar wind experiment data collection concluded on December 27, 1994. This experiment is designed to measure the charged particle environment very near the Sun by measuring the effect of those particles on the radio signal beamed from Galileo to Earth.

The synthesis of results from the radio propagation measurements conducted during the Galileo superior conjunctions and other similar measurements is providing the first global picture of the charged-particle environment near the Sun. The emerging picture is one in which the solar corona is

permeated by a wide variety of ray-like structures that are organized by the large-scale solar magnetic field. During the current phase of the solar cycle, coronal streamers with dense filamentary structure dominate the ecliptic plane, while large-scale coronal plumes pervade the low-density polar regions of the Sun.

Routine Operations and Testing

Routine operations maintenance continued, including Data Management Subsystem (DMS) conditioning, Ultrastable Oscillator tests, an Energetic Particle Detector motor maintenance exercise, Retropropulsion Module 10-N flushing activities, and a Solid State Imaging instrument checkout. Regular science data acquisition from the Extreme Ultraviolet Spectrometer, Dust Detector, and Magnetometer has continued successfully.

Command Tests

Conjunction command tests were successfully performed at Sun–Earth–Spacecraft (SEC) angles ranging from 10.5 to 3.3 deg. Solar conjunction occurred on December 1, 1994.

Telecommunications

Seven Block V Receiver (BVR) tests were performed over DSS-14, the last of a series. The tests successfully demonstrated Block V receiver suppressed carrier acquisition and tracking. A test result briefing covering this series of tests was presented to the Project on January 31, 1995. Full Spectrum Recorder (FSR) tests were also performed over DSS-14/DSS-43.

BVR operations are critical to the continued success of the Galileo mission because of the major improvement in telecommunication performance they offer. By putting all the downlink power in the data channel and eliminating use of a carrier signal, the BVR provides more than twice the otherwise supportable data return at Jupiter. Even with BVR performance below that predicted by lab testing and theoretical models, Galileo will be able to transmit more data at higher rates than those the Block IV receivers could support. As Galileo approaches round-the-net use of the BVR receivers, we look forward to saying good-bye to our worst telecommunication performance.

A variety of routine telemetry tests (Command Detector Unit Signal-to-Noise Ratio tests, Command Threshold tests, Radio Frequency Subsystem Automatic Gain Control tests, and Radio Frequency Subsystem Tracking Loop Capacitor tests) were successfully performed, providing detailed information relative to telecommunication hardware functionality and performance.

Probe Checkout

On March 16, the Probe Abbreviated System Functional Test (ASFT) was performed on the spacecraft (see story, p 1). Playback of Probe ASFT data, including Probe and Relay Radio Hardware (RRH) data, from the tape recorder began on March 18, and completed on April 5, 1995, as planned.

Anomaly Status

AC/DC Bus Imbalance

The AC/DC bus imbalance measurements have not exhibited significant change throughout this period.

Uplink Generation

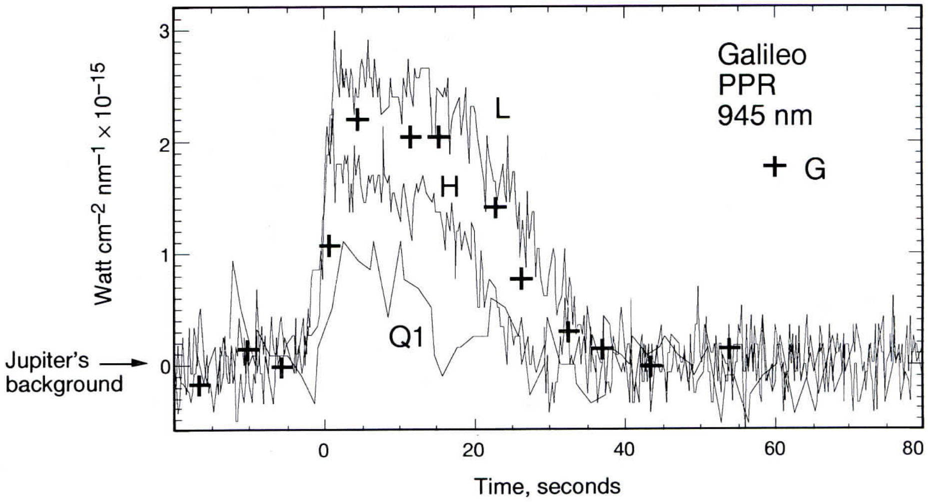
The Project approved Orbit Profiles for the G1 and G2 orbits, the C3 Orbit Activity Plan, and Trajectory Correction Maneuver 23 (which was subsequently executed successfully). ■

Galileo Mission Summary*

Distance from Earth	696,248,400 km (4.7 AU)
Distance from Sun	777,815,800 km (5.2 AU)
Heliocentric Speed	27,300 km/h
Distance from Jupiter	124,770,600 km (0.8 AU)
Round-Trip Light Time	77 min, 20 s
System Power Margin	47 W
Spin Configuration	Quasi all-spin
Spin Rate/Sensor	2.89 rpm/Star Scanner
Spacecraft Attitude	Approximately 6 deg off-Sun (leading) and 3 deg off-Earth (leading)
Downlink Telemetry Rate/Antenna	10 bps (coded)/LGA1
General Thermal Control	All temperatures within acceptable ranges
RPM Tank Pressures	All within acceptable ranges
Powered Science Instruments	Plasma Wave Spectrometer, Extreme Ultraviolet Spectrometer, Ultraviolet Spectrometer, Energetic Particle Detector, Magnetometer, Heavy Ion Counter, and Dust Detector Subsystem
RTG Power Output	498 W
Real-Time Commands Sent	273,041 commands

* All information is current as of April 13, 1995.

A Comet's Fiery Dance at Jupiter



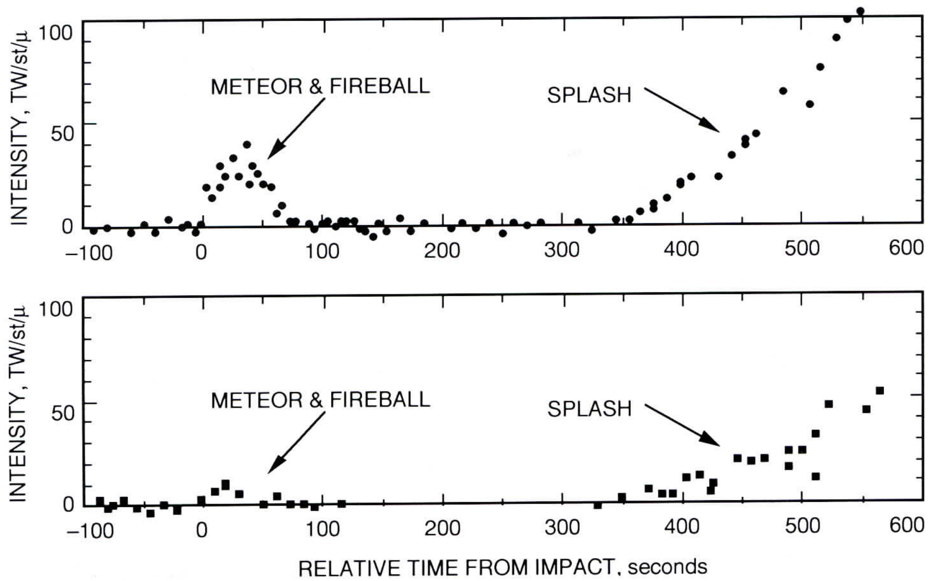
Light curves for impacts G, H, L, and Q1 as seen by Galileo's Photopolarimeter/Radiometer. The dramatic increase in radiation (from 0 to 40 seconds) is thought to arise from the fireball phase of the events, immediately following entry of the comet fragments into the Jovian atmosphere.

Scientists are still piecing together the details of what happened when comet Shoemaker–Levy 9 collided with Jupiter in July 1994. The final data playback from Galileo, covering onboard observations of comet fragments R and W, was completed in late January of this year.

Collision events have thus far been divided into three phases: The incoming comet fragment first hits the Jovian atmosphere and heats up (the "meteor" phase), then explodes into a fireball of extremely hot gas (the "fireball" phase). The gas backflushes out the tunnel cleared by the incoming fragments, and the gas and debris expand, rise, and cool, forming the plumes seen above the Jupiter limb by the Hubble Space Telescope and ground-based observers. Then the plume ejecta—a mix of cometary and atmospheric material—fall back toward the planet, heating the atmosphere and producing intense thermal emissions (the "splash" phase).

Images from Galileo's Solid-State Imaging (SSI) camera show both the flash of the comet fragments colliding with the Jovian atmosphere and the initial hottest phase of the resultant explosions and fireballs. The latest SSI returns confirmed a characteristic brightness profile in the meteor and early fireball phases for fragments K, N, and W: peak brightening at 0.56-µm (green) and 0.889-µm wavelengths was observed less than 10 seconds after initial detection, then the object faded for some 20 seconds, until contact was lost. In addition, initial peak brightness pulses for K, N, and W were within a factor of 2 of each other. Given such a similarity in brightness profiles among these events, it is still a mystery as to why there are significant differences in the longer lasting effects observed from Earth.

Based on data from Galileo's Near-Infrared Mapping Spectrometer (NIMS), we know that the super hot fireballs associated with fragments G and R lasted about 1 minute (before cooling sufficiently to be invisible to NIMS).



NIMS light curves at 4.38 µm for the G (top) and R events. The fireball phase (0–60 s) and the beginning of the splash phase (at 350 s) are evident for both events. The G impact occurred at 07:33:32 UT (Universal Time), Earth Received Time, on July 18, 1994, derived from Galileo's Photopolarimeter/Radiometer data. This is the time at which an observer on Earth would have seen the events. Because Galileo was much closer to Jupiter than the Earth was, the spacecraft actually recorded the events sooner than Earth-based observers. The R reference time, which is derived from NIMS data, corresponds to 05:35:08 UT on July 21, 1994. Although the R timing reference is uncertain, the probable error is small.

We also know (from NIMS) that the plume ejecta began falling back into the atmosphere about 6 minutes later, getting brighter and brighter for the 3 minutes observed. Ground-based data indicate that the total splash phase for each of the two fragments lasted about 10 minutes, with peak brightness at a wavelength of 4.38 μm reached at about 5 minutes after initial detection. The 6-minute flight time implies that the ejecta exploded out of the atmosphere at a minimum vertical velocity of 4.3 km/s, with particles reaching at least a 380-km vertical height.

The similarity in the G and R event timelines—confirmed by ground-based observations—is surprising since the G fireball was four times brighter than the R fireball, and the G splash was about twice as intense as R's. (Based on an assumed comet density of 1 g/cm^3, fragment G must have been at least 150 meters in diameter prior to impact.) The time similarity suggests that the ejecta flight time was determined by fireball and plume physics, not by observational geometry or the mass of the incoming comet fragments.

Preliminary analysis of NIMS spectra suggests that the splash material contains OH, which could be the hot remnants of water (H_2O) molecules from the vaporized comet or from Jupiter's presumed water clouds, as well as CH, which may indicate atmospheric methane or comet-derived hydrocarbons as the emitting source. These preliminary findings may also offer an explanation as to why the immense black patches are persisting in Jupiter's high atmosphere. The black patches may be composed of micrometer-sized carbon particles derived from comet or atmospheric materials, which would linger for about 1 year from the beginning of the splash period—acting much like volcanic dust in Earth's stratosphere. Another possibility is that the patches contain sulfur that erupted from a lower cloud layer of condensed ammonium hydrosulfide.

Further analysis of the available data—perhaps supplemented by new information from Galileo as it nears the Jovian system—should help answer many of the questions that remain about comet Shoemaker–Levy 9 and its fiery destruction at Jupiter. ■

— Scott Bowdan

Q & A

Q Why aren't we taking an image of the Probe as it drifts away from the Orbiter after separation?

A Imaging the Probe as it drifts away from the Orbiter was contemplated both for engineering assessment (that is, looking for any problems with the Probe hardware) and optical navigation. In order to assess the external condition of the Probe, detailed pictures would be desirable, but, because the SSI is focused on infinity, objects up close would be out of focus. In fact, by the time the Probe is in focus (at about 18 km away from the Orbiter), it would only be about 2 to 3 resolution elements across—not very detailed!

Taking a picture of the Probe for optical navigation purposes appears to be feasible, but, because the Probe delivery knowledge requirements are being met and because of the operational costs of trying to return imaging, it was decided not to pursue optical navigation.

Q Once the Probe separates, what wakes it up many months later just before entry? Does it just have a built-in programmable timer, or does the Orbiter beam the Probe a command to wake up? Or does it remain fully "awake," doing the same thing (that is, taking data) from the time it separates until the end of its mission?

A The Probe does have a built-in, programmable timer, which is set by ground command shortly before the Probe separates from the Orbiter. The mission designers wanted to have some flexibility in starting the timer to accommodate any late changes in the Probe release schedule. If Probe release is delayed for any reason, the timer is reset appropriately. The timer is the only thing running on the Probe during its 5-month cruise to Jupiter.

Like an alarm clock, the timer is set to wake up the Probe 6 hours before entry into Jupiter's atmosphere so that the Probe can (1) take measurements of the inner magnetospheric energetic particle environment and (2) listen for radio emissions characteristic of lightning (these actually sound like long, descending whistles).

This "pre-entry" phase ends when the Probe's accelerometers detect signs that the Probe is being decelerated by Jupiter's atmosphere. At this point, the Probe starts its entry/descent phase.

PROJECT MANAGER from page 1

the Probe descent profile and showed adequate capacity for the full-up Probe nominal mission including the pre-entry science measurements. On March 16th the newly loaded Phase 1 Orbiter Flight Software was used to perform the final inflight checkout of the Probe. The checkout results were perfect. Based on the excellent ground battery test results and the Probe checkout, we will command the Probe to perform its nominal mission. This is done by the Orbiter a few days before it releases the Probe. (Once the Probe is released, it can no longer be commanded.)

One of our biggest challenges over the last several months has been the Orbital Operations (Phase 2) Flight Software (FSW) development. We have been very ambitious in working with the science investigators to maximize the capability of this new software to do the best possible job within the limits of the onboard processors and available memory. Near the end of last year, we had fallen seriously behind schedule. Through a most extraordinary effort, the Development team has effectively recovered and now has a version of the Phase 2 FSW containing representations of all core capabilities in system testing in the Spacecraft Testbed. This recovery also involved substantial augmentation of test teams (and very long hours for all involved) and testing platforms—most notably maximum use of the high-speed simulator called FASTSIM developed under the leadership of the late Dr. John Zipse. We now have good reason to expect delivery of the first "flyable" Phase 2 FSW in July as planned.

Over the past year, we have been working intensely with our colleagues at DARA (the German Space Agency) and DASA (Daimler–Benz Aerospace; formerly Messerschmitt–Bolkow–Blohm (MBB)) in preparing to use Galileo's 400N main rocket engine. (Germany is our international partner in Project Galileo, having supplied the entire Galileo propulsion system and several science instruments.) The Orbiter Deflection Maneuver (ODM) which targets the Orbiter to its Jupiter/Io aimpoint is now scheduled for July 27th (two weeks after Probe Release) and this will be the first inflight use of the 400N engine. The JPL/DARA/DASA team has studied every potential engine and feed system fault and developed the most comprehensive contingency action plan feasible. Extensive tests of a flight-identical engine were performed in Germany to demonstrate contingency operating capabilities. Further testing of feed-system components was also performed. Our Plan specifies how we will operate the 400N engine for both ODM and Jupiter Orbit Insertion (JOI) for all credible faults. It has been endorsed and complimented for its thoroughness by a Review Board of outside experts.

The so-called Critical Engineering Sequence, which is designed to perform the Probe-Orbiter Relay and JOI "no-matter-what!", has also been vigorously worked over the past year and is now essentially completed and under Project Change Control. Only vernier adjustments are anticipated.

Concurrent with all the preparations for arrival, development of the detailed spacecraft operating sequences for each of the Jupiter/Satellite encounters of the Orbital Tour has been ongoing since last August. These sequences contain all the scientific observations, the required engineering activities, and planning windows for the orbit trim maneuvers. A very substantial fraction of the Flight Team has been working tirelessly and diligently on this demanding, longer range effort. The sequence for the fourth encounter (E4) of the ten encounter tour is nearing completion. These products are impressive and are the instructions to the spacecraft for meeting our scientific objectives in Jupiter orbit.

Trajectory Correction Maneuver (TCM) 23 was flawlessly performed on schedule April 12th. TCM 23 adjusted the Spacecraft trajectory so that after the Probe is released it will nominally be on a ballistic path to the center of its Jupiter entry corridor. The accuracy of the entry path will now be mainly determined by the accuracy of the prerelease spin-up and the Orbiter–Probe separation springs impulse.

In closing, I am delighted to report that Project Galileo has recently received two more prestigious awards. *Aviation Week & Space Technology* named Galileo in its 1994 Laurels for our Shoemaker–Levy 9 Jupiter impact observations and our discovery of Ida's moon Dactyl, and we have just received the NASA Group Achievement Award for our Ida encounter and Dactyl discovery.

Jupiter awaits! ■

— Bill O'Neil
Project Manager

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The Galileo Messenger

Issue 37 September 1995

From the Project Manager

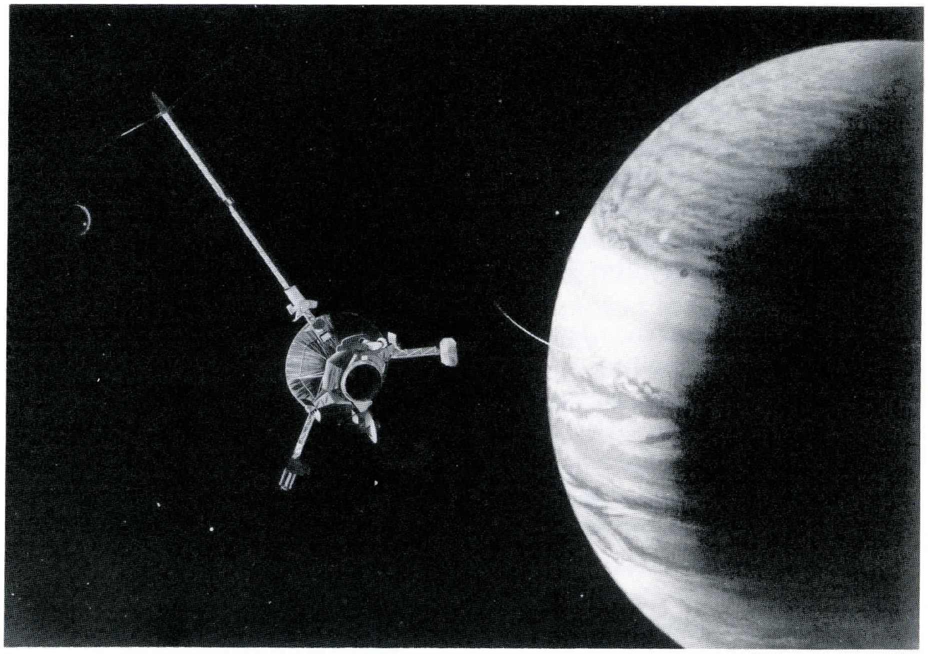
We have had a wonderfully successful and productive summer.

The Probe was flawlessly released from the Orbiter as scheduled the evening of July 12th. The Probe is in perfect condition and on a trajectory and attitude well within specification. The Orbiter control of the spacecraft pointing and wobble at release was so good that the Orbiter made essentially no contribution to the Probe entry angle-of-attack (AOA) error. This is particularly satisfying because AOA turned out to be the hardest parameter to control and it demonstrated conclusively the high-spin spacecraft dynamic model corrections made after the 1993 spin-up demo. Navigation performance for the probe targeting was so good that the final pre-release TCM (24) scheduled for June 23rd was cancelled; the trajectory following the April 12th TCM-23 was already essentially perfect.

It was delightful to see a packed house ("standing room only" would be an understatement) of family and friends in von Kármán Auditorium on Release night to share in the excitement of this truly historic event.

The orbiter deflection maneuver (ODM) was executed exactly as planned on July 27th. Because this was the first inflight firing of the 400-N main engine, the ODM

—see page 12



Jupiter at Last! Galileo's Longest Day: December 7, 1995

Come with us aboard the Galileo Orbiter and leap into the future. It is Arrival Day, December 7, and the view from here is out of this world!

The Longest Day Begins

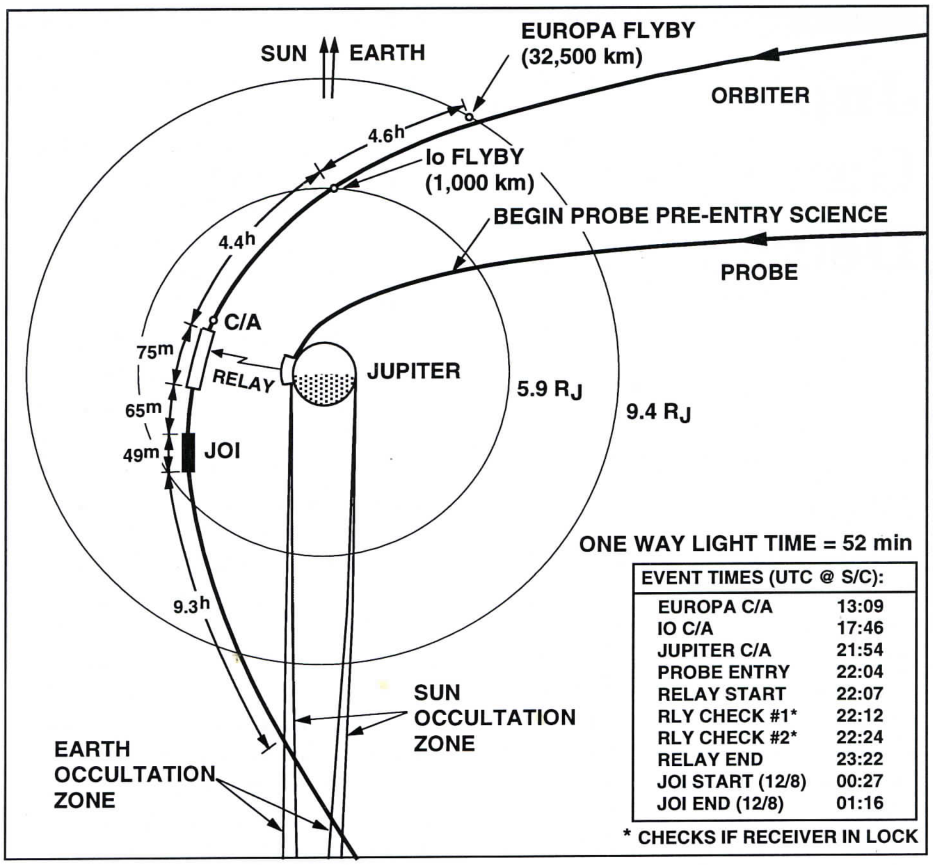
It's now about 5 A.M. PST, December 7 (or 1300 UTC, spacecraft event time) and about 8 hours from perijove (our closest approach to Jupiter). We're near the orbit of Europa, the second closest of the four Galilean satellites. Of course, because the Orbiter is so far from Earth, reports of the day's events to the folks back in Pasadena will be delayed 52 minutes, the one-way light time (the time it takes for a radio signal to travel between Jupiter and Earth). At this time, the signal will arrive at the Deep Space Station (DSN) at Madrid. From the Orbiter, the Earth is lost in the Sun's glare, appearing less than 2 degrees from it.

After 2240 days en route, the Galileo Orbiter and the Probe it released 147 days before have arrived in the Jovian system. The preliminary phase, Jupiter Approach, began 2 months ago, when the Orbiter took a global

image of Jupiter (with the probe entry site in view), followed by a series of optical navigation frames. As the day approached, the Orbiter became increasingly active, probing for the Jovian magnetosphere's bow shock, scanning the Io plasma torus in extreme ultraviolet, and examining dust in the Jovian neighborhood. The previous 24 hours were especially busy with the ultraviolet spectrometer (UVS), the solid-state imaging (SSI) camera, the near-infrared mapping spectrometer (NIMS), and the photopolarimeter radiometer (PPR) looking at Jupiter, the Galilean satellite Io, and the minor satellites Thebe and Adrastea.

The 24 hours of Arrival Day—from flybys of the satellites Europa and Io, to probe relay, to Jupiter orbit insertion (JOI), and finally to a radio occultation of Jupiter—will be the busiest by far in the whole mission. On Arrival Day, the Orbiter will swing right through the heart of the Jovian system. While the opportunity for unique science will never be greater, the Orbiter must perform two critical activities (probe relay and JOI) in the most hostile radiation it will ever face. But, thanks to a truly tremendous effort by its flight team, Galileo has never been more ready to fulfill its mission.

Galileo flies by Europa some 32,500 km above its icy surface. At this distance, Jupiter looks about the size of a cantaloupe held at arm's length and Europa, about the size of a tennis ball. Even though objects in this part of the solar system get only 4 percent of the sunlight we get on Earth, Europa still looks very bright, like a half-lit, gleaming white snowball. The surface is remarkably smooth, with no discernible craters or mountains, just an intricate, frozen webwork of long, brownish cracks or streaks. The Orbiter will visit Europa later on several much closer, targeted passes, but this will be the only one at such high southern latitudes for an unobstructed view of its pole. All the science instruments are busy collecting data, but we won't be sending any back to Earth for some months. On Arrival Day, all the science data are stored in the 900 megabits of the Orbiter's recorder. Three of its four tracks store science data intermittently from five days out through about a half hour beyond Io; then, the remaining track records all the probe data as well as the engineering telemetry and low-rate science to an hour and a half beyond JOI.



Orbiter Arrival Day at Jupiter, December 7, 1995. Times are in hours and minutes. C/A is closest approach (perijove); R_J is Jupiter radius (71,400 km).

The Io Flyby

We fly by Io less than 5 hours after Europa. The DSN station at Goldstone picks up the signal now. This is our only close flyby of this violently volcanic moon, because radiation levels inside the orbit of Europa are just too dangerous. We expect the Orbiter to absorb anywhere from 50 to 100 krad, maybe a third of the total expected radiation dose for the whole 2-year tour at Jupiter, on this single day! This is a lot of radiation: 1 to 2 krad is considered lethal for humans. High radiation plays havoc with electrical systems and showers our instruments with a lot of "noise." The biggest danger would be a random "bit flip" that could generate a false command. While our systems have been specially hardened in anticipation of this exposure, we still don't know just what to expect. When we take pictures, we're operating in a specially designed mode to record images faster, recording an image in 2-1/3 seconds to clear the SSI's charge-coupled device before radiation snows it over.

Io has been described as looking like a pizza, or a diseased orange. The surface is covered with white, yellow, orange, red, and black features—most likely allotropes

and compounds of sulfur spewed out by the constant volcanic eruptions. We swoop within 1000 km of the tortured surface, so close the disk fills our field of view and the SSI shows objects as small as 40 m across. We look at several specially targeted areas like Colchis Regio and the volcanos Volund and Prometheus. Our closest approach is just over the terminator (where the night and day sides meet), so the shadows are long and the relief shows well.

The Io flyby is also critical for JOI: passing in front of Io in its orbital path delivers a gravity-assisted brake on Galileo's trajectory. The reduction in the Orbiter's speed (its ΔV) by 175 m/s accounts for about a fifth of the total change needed for the capture orbit, the first in the orbital tour.

After its closest approach to Io (spacecraft event time 9:46 A.M. PST), Galileo has only a half hour for a backward glance. As we depart, the sunshade over the scan platform begins to obstruct our view. A turn maneuver for a better look is out of the question with the probe relay coming up; still, the NIMS looks for Loki's plume on the limb, and the PPR scans the dark side in several thermal and polarized bands.

The fields and particles instruments—the magnetometer, dust detector, plasma detector, plasma wave sensors, energetic particles detector, and heavy ion counter (see story, p. 8)—have been busy collecting data on the ring plane and the inner magnetosphere, especially the Io plasma torus. This plasma-filled donut, fed by constant volcanic eruptions, encloses Io's orbit with a lethal fog of high-energy, charged particles. It is one of the more bizarre objects in the solar system and has been called by Lou Frank (who chairs the Magnetosphere Working Group) the "beating heart of the Jovian magnetosphere." Also, the Orbiter's dust detector may find some debris even though Jupiter's known ring lies some 150,000 km below us. Because data from these instruments are recorded at the relatively low rate of 7.68 kb/s, the instruments can collect data from Europa until more than an hour beyond JOI, almost 14 hours for a good section of the torus and the ring plane.

The Probe Relay

When the Orbiter crosses Io's orbit, the Probe is already active. An hour later, it turns on its first instrument, the lightning and radio emission detector and energetic particles instrument (LRD/EPI) (see story, p. 10). The two parts work together, take samples several times before entry, and store their data in the Probe's memory. These data are relayed back to the Orbiter during probe descent while the LRD continues to relay new data on lightning in the Jovian atmosphere.

About 4 hours after Io, the Orbiter reaches perijove, where the banded face of Jupiter bulks as large as a basketball (at arm's length). Ten minutes later (2:04 P.M. in Pasadena), the Probe hits the top of the Jovian atmosphere, about 450 km above the 1-bar level (pressure at sea level on Earth) at the comet-like speed of 47 km/s. DSN stations at both Goldstone and Canberra have been tracking the event.

The Probe enters at a shallow (8.6°) angle in the equatorial zone of rising air and pale-colored clouds. From down inside Jupiter's atmosphere, the Probe is a spectacular fireball, streaking east out of the setting sun and towards the gathering night. In about a minute, deceleration in the thickening hydrogen–helium atmosphere pushes the tiny Probe's weight up nearly 230 times as the heat shield glows white hot at 15,000 K. Two minutes into entry, the Probe has slowed from Mach 75 to Mach 1 (local speed of sound), slow enough to deploy its parachutes—first a tiny drogue, then the main chute—and drop what's left of the heat shield (lighter now by more than half from ablation). Three minutes past entry, the Probe, now swaying beneath its main chute (and weighing 2-1/2 times what it weighed on Earth), establishes radio link with the Orbiter, more than 200,000 km overhead.

Pointing the Orbiter's antenna is of prime importance in establishing the radio link, and the Orbiter depends on its gyros to maintain inertial attitude. The primary backup is the star scanner, which normally uses a three-star set. But the high radiation environment at four Jovian radii may interfere with the usual attitude-control strategy. That's why the Orbiter now carries the new Attitude and Articulation Control System (AACS) flight software to enable it to establish its clock angle (measured around the spin axis) with the first-magnitude star Canopus. For secondary clock-angle backup, the Orbiter can also use sun pulses.

The parachute descends. When the Orbiter first picks up its signal, the probe should be 30 or 40 km above the 1-bar level, in the early Jovian evening, dropping through a frigid brown aerosol haze just above the tops of the white ammonia ice clouds. The 256-b/s signal from its six instruments reports the sunlight and heat input, pressure, temperature, cloud structure, lightning activity, and composition of the atmosphere. The Probe's ultrastable oscillator controls the signal's frequency, so measurements aboard the Orbiter of Doppler shifts in the Probe's signal give information on wind speed and direction as the Probe drifts down through the thin layer of ammonium sulfide clouds, and the thicker billows of blue-white water clouds. After some 30 minutes, it finally drops into the zone below the clouds at the 7- or 8-bar level, maybe 80 km below 1 bar, where

the temperature should exceed 310 K (around 100°F).

At this time, the Orbiter's probe relay antenna slews to compensate for the Probe's changing position below it. It will slew three more times at 10-minute intervals to maintain lock. As the Probe sinks even lower, it continues to send its data until the thickening gases block the signal or the battery gives out (after only 75 minutes of life). Here, 163 km down, the Probe's weakest components may already have succumbed to the scorching 465-K heat or the crushing 30-bar pressure. Whatever the Probe's fate, the Orbiter can listen for only 75 minutes; the critical JOI burn approaches, and the Orbiter must give that event its full attention.

JOI

For orbit insertion, orientation and timing are critical. The JOI burn is not like the orbiter deflection maneuver (ODM). At ODM there was a wide window and considerable margin for error; at JOI, there is none. The Orbiter has only one chance to do it right. And because of the 52-minute one-way light time (longer than the engine burn itself!), the Orbiter has to do it all on its own. To guarantee orientation and stability during the burn, the spacecraft spins up to 10.5 rpm. Timing the burn on the 400-N engine is likewise safeguarded. The planned 49-minute burn is regulated by accelerometers that automatically shut the engine down when the change in speed reaches 643 m/s. So, if the burn is a little faster or slower than expected, the system compensates. If the accelerometers drift, timers shut the engine down no sooner than a preset time, but before it can burn too long.

The burn, which begins about an hour after the end of probe relay (4:27 P.M. PST), automatically cuts off (at 5:15 P.M. PST) less than an hour before the Orbiter recrosses the orbit of Io. JOI is being tracked by Canberra. The folks back in Pasadena will learn of this a bit after 6 P.M. The Orbiter continues to record fields and particles data for another hour and a half to complete the work on the near-Jovian environment.

Radio Occultation

Nine hours after engine cutoff, the Earth disappears behind the disk of Jupiter. One hour and twenty minutes before this occultation, the Orbiter prepares by increasing the signal strength in the main part of the radio signal. As the signal gradually fades and bends in the thick Jovian atmosphere, the DSN will record the signal at its complex in Madrid. The Radio Science Team will later analyze the data to develop temperature and pressure profiles of the gases through which the signal passes. The recording will continue until the signal is completely blocked by the planet. And then the Orbiter flies alone, the link to Earth broken. Fifty minutes later, the Sun passes behind the disk of Jupiter too, and the Orbiter flies in the dark. Finally, after 3-1/2 hours of radio silence, the Earth reappears to the Orbiter and the Deep Space Network reacquires the orbiter signal for the Radio Science Team to analyze. It's 6 A.M. PST, December 8. One hour and twenty minutes later, the Orbiter telemetry is reacquired, and the flow of data resumes.

This ends Galileo's longest day. If everything has gone according to schedule, the Orbiter is now on its 7-month first orbit in the Jovian system. It carries a load of data from the probe mission, the inner magnetosphere, and encounters with Jupiter and four satellites. It will begin to play the probe data back to Earth just after its first post-JOI orbit trim maneuver on December 9. All probe data will be in hand by mid-March 1996, and the rest of the recorded data will be returned by mid-July. With these last Arrival Day duties completed, Galileo can now look forward to the first 2 years (the prime mission) of a long, interesting, and history-making tour. ■

—Larry Palkovic

"The Morning After" Press Conference

"Another excellent accomplishment in a long string of accomplishments by the Galileo mission!" said Don Ketterer, NASA's Galileo Program Manager, at the July 27 press conference held at JPL. Full-scale models of the Galileo spacecraft and its Probe could be seen in the background as viewed on the television monitors.

It was the morning after the orbiter deflection maneuver (ODM), the first major use of the 400-newton engine—so essential for performing two key maneuvers still to come, the Jupiter orbit insertion (JOI) and the perijove raise maneuver (PJR). Bill O'Neil, Project Galileo Manager, expressed his delight, "This is a joyous morning. . . . Therefore, the excellent propulsion system worked beautifully. First the probe release—and now another excellent event." After this first operational sustained burn, both vehicles were on the proper trajectories to Jupiter. The Probe had been released two weeks

earlier. Marcie Smith, Galileo's Probe Manager at NASA's Ames Research Center, added, "The Probe is on target and fully configured, heading for encounter at Jupiter."

A warm welcome was given to the assembled guests from the Federal Republic of Germany; representatives of Daimler Benz Aerospace AG (DASA) (formerly Messerschmitt–Bolkow–Blohm), designers and builders of the propulsion system; Deutsche Agentur für Raumfahrtangelegenheiten (DARA), a German space agency that manages the contract with DASA; and Deutsche Forschungsanstalt für Luft- und Raumfahrt (DLR), a German research agency that conducts the day-to-day operation of the propulsion system. Included in this recognition of success were personnel from Ames, who manage the Probe, and from Hughes Space and Communications Co., who designed and built the Probe.

The Orbiter Deflection Maneuver

At 12:38 A.M. Pacific Daylight Time (Earth-received time), the 400-N engine fired for 5 minutes and 8 seconds, slowing the Orbiter by 61.1 m/s and altering the trajectory to bring the Orbiter above the Probe, ready to receive data. The 400-N retropropulsion engine (television viewers watching the press conference were treated to a view of a duplicate engine) uses the same propellent as the 10-N thrusters: monomethyl hydrazine (MMH) and nitrogen tetroxide (N_2O_4) stored in two tanks each; the feed system pressurization gas is helium.

The ODM could have been accomplished by the 10-N thrusters usually assigned for trajectory correction maneuvers (TCMs). Why did the Galileo team opt to use their one and only 400-N engine for this trajectory change? Because, until its release, the

—see page 6

Probe Release, A Night to Remember

On the evening of July 12, the successful probe release was the climax of an evening of fun and anticipation as Project Galileo friends and family crowded von Kármán Auditorium. After a review of the Probe's mission by host Jan Ludwinski (Chief of Mission Planning) and co-hosts Lou D'Amario (Deputy Chief for Navigation), Gary Kunstmann (Deputy Engineering Office Manager), and Dan Carlock (Hughes Aircraft Company analyst, Probe Engineering Team), guest speakers Bill O'Neil and Dr. Ed Stone contributed to the festivities.

Fun was provided by the Not Ready for Real-Time Players (team members all) who amazed the audience with their rendition of the Orbiter's song (to the tune of "Turkey in the Straw"):

"Probe in the bay, sent it on its way,
Sayonara baby, we'll meet again some day,
I pointed you for entry and I gave you a good spin,
I'll be glad to catch your signals as you are going in."

And then the Probe's refrain (to the tune of "Release Me"):

"Please release me, can't you see,
You have your own trajectory,
For years we've wandered to and fro,
But now, it's time to let me go."

Video animations, provided by the Digital Image Animation Laboratory, simulated the release taking place 789 million km away. Release was accomplished as the three pyrotechnic separation nuts fired and the springs nudged the Probe away. Anticipation heightened as the crowd waited from 10:30 P.M. PDT when the Orbiter released its Probe until the final 10-s countdown, ending when the confirmation signal arrived about 37 minutes later (time for the radio signal to travel at the speed of light). Another milestone passed.

The Not Ready for Real-Time Players in a rare appearance at the Probe Release celebration.

PRESS CONFERENCE from page 5

Probe sat directly in front of the 400-N engine nozzle, precluding any inflight checkout. With the Probe on its way, the 400-N engine could finally, after almost 6 years, demonstrate its operational capability, in advance of the crucial maneuver to occur at Jupiter, the JOI.

And what a demonstration it was! From 0 to about 97 km/h in 135 seconds. The burn was 1.2 percent less than predicted but well within the permissible 6 percent. For the past 2 years, the Galileo team has been checking and preparing scenarios for every possible contingency. None of these plans had to be implemented. A joyous Bill O'Neil said, "This flawless maneuver gives us the confidence that the 400-N engine is ready to perform orbiter insertion at Jupiter and the perijove raise maneuver to follow. We have a beautiful system."

Probe Release

Marcie Smith recounted the story of a healthy Probe—released on schedule—that had "worked perfectly for all tests." It had been turned on six times during cruise, and ground batteries tested under conditions simulating those onboard the Orbiter indicated ample power will be available for the probe descent into the clouds of Jupiter.

Since execution of the command to sever the umbilical cable that united the Orbiter and its Probe, there can be no communication until, during descent to Jupiter, the Probe relays its data via radio to the Orbiter, a one-way "conversation." The Probe will coast 82 million km until 6 hours prior to arrival on December 7, when a timer will activate systems and instruments in preparation for the entry and parachute descent. Entry speed will be 170,600 km/h or 47 km/s—100 times the muzzle velocity of a bullet fired from a 0.45-caliber gun. This will be the highest impact speed ever to be experienced by a manufactured object. It must then undergo extremes of deceleration, temperature, radiation, and pressure.

Today, the Galileo team continues to prepare for the final approach to Jupiter (see story, p. 1) buoyed by their successes in probe release and the ODM. Again, the news has been good—the reason for all those smiling faces at Project Galileo on *the morning after*. ■

Educational Outreach Corner

As Arrival Day draws near, Galileo's Educational Outreach activities are stepping up.

October Workshops

For those in the Southern California area (or anyone interested in a weekend jaunt), there will be a Galileo Jupiter Arrival Preview Educator Workshop on October 29, 1995, from 1–5 P.M., at JPL.

The workshop will follow a weekend-long Ulysses educator's workshop, both of which are free. For additional information, contact David M. Seidel at david.m.seidel@jpl.nasa.gov or the

Teaching Resource Center
Jet Propulsion Laboratory
MS CS-530
4800 Oak Grove Drive
Pasadena, CA 91109-8099
(818) 354-6916.

Online From Jupiter

Interested in exploring the solar system and Jupiter? Curious about what it's like behind the scenes, working on NASA's Galileo mission? Then, you'll want to tune in to Galileo's new Online From Jupiter, coming to the Internet in mid-October. Online From Jupiter will share the real-time experiences of Galileo's flight team participants with K–12 classrooms and others. From mid-October through January, you'll be able to read the journal entries written by members of the flight team, describing their work. You'll have a front seat for the excitement surrounding arrival at Jupiter (on December 7) as scientists and engineers monitor Galileo's receipt of the precious data from the spacecraft's atmospheric Probe and the main spacecraft's entry into orbit around Jupiter. After reading the journal entries and background material, K–12 students and teachers can ask project members questions (via e-mail) from late November through January—and receive personal responses (which will also be made publicly available).

For more information, send e-mail to

info-jup@quest.arc.nasa.gov

or set your World Wide Web browser to

http://quest.arc.nasa.gov/jupiter.html

Online From Jupiter will be available to non-World Wide Web users, too, via FTP, Gopher, and others.

On Arrival Day itself, mission commentary will be broadcast on NASA television starting about 10 A.M. PST on December 7, 1995. Interviews with project scientists and engineers will be interspersed with mission status reports throughout the day. ■

A Communiqué From Somewhere in Outer Space

Overheard on the World Wide Web

Project Galileo Science Group

Attention:
Project Scientist Torrence Johnson
Probe Scientist Rich Young

To My Esteemed Fellow Scientists,

From my current perspective, I have been steadfastly observing the travels of your spacecraft and my namesake, Galileo. How fortunate you are to live at such a time of discovery and truth seeking. Yes, Copernicus and his followers understood the Sun to be the hub of the revolving planets. But many of my contemporaries who accepted the Ptolemaic system believed that the Earth must be stationary, for if it moved, the Moon would be left behind!

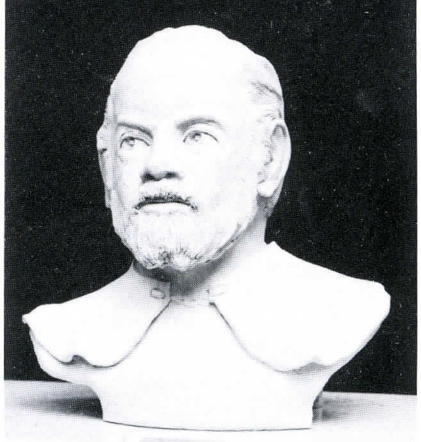
We needed knowledge—and thirsted for it. To better view the sky, it occurred to me that Hans Lippershey's Far Looker device, so useful on the battlefield, might aid me. I set to work grinding the necessary lenses and with my own telescope (now 30 power) soon beheld that magnificent celestial body—Jupiter. It was a January night in 1610, so long ago! Imagine my surprise at seeing star-like bodies in the planet's immediate vicinity. My surprise became amazement during subsequent viewing when I saw that they followed Jupiter across the sky. You no doubt have read my notebook describing the change in their relative position over the following few weeks.

Here was the proof we followers of the Copernican theory needed: celestial bodies that are in motion can themselves be centers of motion. Yes, it is possible for the Earth to orbit the Sun and for our Moon to orbit the Earth. I realized that Jupiter and its moons (now named Io, Europa, Ganymede, and Callisto) could serve as a model, a miniature solar system. As you know, I made many observations and was rewarded with seeing the Sun's spots, peaks and valleys on our Moon, and, over time, the phases of Venus. How I longed to see more. . . .

Yes, that was a beginning of sorts, but you are the future. For you, the Pioneers and Voyagers have pointed the way. Soon the Galileo spacecraft will be arriving at Jupiter with its host of instruments, each a marvel in itself. What wonders they will reveal! But it will be up to you to interpret and explain the data they provide. This is the pleasure of discovery and its awesome responsibility.

For me, the truth was costly. At first, only the science community took much notice of my celestial discoveries as reported in <u>*The Starry Messenger*</u> *(1610), but 22 years later, my* <u>*Dialogue Concerning Two Chief World Systems*</u>*, admittedly biting in its sarcasm, caused quite a commotion. The contrast I drew between the Copernican and Ptolemaic systems clearly showed the folly of the old view.*

Unfortunately, my refusal to follow the Church's requirements on teaching of the world systems led to my house arrest; it devastated me at the time, though it did allow me to focus my energies on the development of the scientific method. It has been my great satisfaction to note how the discipline of science has grown from that seed, influencing endeavors such as yours. While imprisoned I also had my poetry and my music. Always an inspiring companion, the lute comforted me much in those final days of blindness.



Galileo Galilei 1564 - 1642

The times are different now. You may have seen the commemorative coin struck in 1982 to honor the 350th anniversary of the <u>*Dialogue*</u>*. Moreover, in 1992, Pope John Paul II concluded a retrial of my case, wherein the Church upheld the rightness of my world view. Surely, this event has done much to heal the disharmony between science and religion since my first trial over 350 years ago.*

In December, the maneuver for placing the spacecraft into orbit and the data received will once again show the watching world the simplicity, the beauty, and the power of the sciences, especially physics and mathematics. Who knows what will be learned from this exploration—undoubtedly, something of the evolution of our solar system—and possibly, the universe itself? On to Jupiter!

I remain forever
your humble servant,

Galileo Galilei

Meet the Fields and Particles Science Group

"What is unique about science representation on flight projects such as Galileo," said Group Lead Kim Spelts, "is that operations are performed by a mixture of systems engineers and scientists." The 11-member Fields and Particles Science Group (FPSG) possesses a diverse set of skills. Group members come from backgrounds in computer science/aerospace engineering or are scientists with backgrounds such as astrophysics, physics, or astronomy. The purpose of the group is to design the spacecraft command sequences that carry out the magnetospheric science objectives of the Project Science Group (PSG). The FPSG accomplishes this by interacting with the experiment investigators to develop a set of science observations and measurements that fit within the resource constraints of the mission and then developing corresponding command sequences for the instruments.

The hard-working FPSG on their morning break. . . . Future Farmers of Jupiter? Aboard the tractor (from left to right) are Scott Bolton, Carol Polanskey, Claudia Alexander, and LeRoy Larry in the top tier; Kim Spelts, Yi Mei, Neil Murphy, and Leo Cheng in the mid tier; and Duane Bindschadler and Steve Levin in the bottom tier (B-G Andersson is not pictured).

The FPSG is responsible for the successful operation of six instruments onboard Galileo. These instruments are the magnetometer (MAG), dust detector (DDS), energetic particle detector (EPD), heavy ion counter (HIC), plasma science instrument (PLS), and plasma wave subsystem (PWS). Together, these instruments will provide the most complete picture ever of the interaction of dust and charged particles between Jupiter, its satellites, and the Sun. "Jupiter has arguably the most complex magnetosphere in the solar system," said Magnetospheric Working Group (MWG) representative Scott Bolton. "Jupiter's magnetosphere is also the largest object in the solar system—at times, its tail reaches all the way back to Saturn's orbit."

Three JPL teams are responsible for the instruments. Bolton heads up the PLS/PWS team, assisted by Claudia Alexander, LeRoy Larry, and Steve Levin. The MAG/DDS team Science Coordinator is Carol Polanskey, who is assisted by Duane Bindschadler and Yi Mei. Neil Murphy is the Science Coordinator for the EPD/HIC team, assisted by B-G Andersson and Leo Cheng.

The primary science objective of the fields and particles experiments is to perform a near-continuous survey of the magnetosphere—mapping its structure, studying the dynamics, and gaining a general understanding of the motion of particles within it. "The magnetosphere is full of charged particles called a plasma," explained Bolton. "Plasma makes up about 99 percent of the universe and completely fills interplanetary space as well as planetary magnetospheres. Galileo's

complete magnetospheric instrument package will measure the magnetic field, both low- and high-energy particles, and the electromagnetic waves that can distribute energy between particles."

Understanding the dust environment at Jupiter is an important objective. Of particular interest are charged dust particles (dust with extra or missing electrons). While neutral dust is primarily influenced by gravity, charged dust behaves quite differently—corotating with Jupiter and spinning around the planet much faster than the speed of their neutral cousins.

The Io torus is a primary feature of Jupiter and will be studied in depth by Galileo. The torus, a product of volcanic eruptions on Io and Jupiter's fast rotating magnetosphere, is made up of charged particles and dust whipping around at the speed of Jupiter's rotation (about every 10 hours). The torus particles bombard Io's trailing side as Io orbits at a much slower pace, knocking off particles from Io's surface in the process.

In addition to characterizing the magnetic environment surrounding Jupiter and its satellites, the fields and particles instruments will provide information about the chemical composition of the satellites themselves. By making in situ measurements of the particles that have escaped the planet and its moons or entered into the magnetosphere from the solar wind, an understanding will be gained of what makes up the atmospheres of Jupiter and its satellites. This will complement other measurements taken by remote-sensing science instruments and by Galileo's Probe. "Unlike the remote-sensing science instruments, we are making in situ measurements, which means we are actually getting particles into the instruments to measure them," said Bolton.

The FPSG will have a unique opportunity to collect data about Jupiter's environment, since the instruments onboard Galileo that measure Jupiter's magnetosphere will be the most comprehensive of any mission flown yet. In addition to being in orbit around Jupiter for 2 years, giving the group an opportunity to measure both spatial and temporal changes, the experiments onboard Galileo are far more advanced than Voyager's. The particle instruments are specifically designed to expand on what we learned from Voyager, and the plasma wave instrument senses both electric and magnetic waves. Galileo also added a dust instrument, which the twin Voyagers didn't have. The last major objective of the FPSG will involve the passage through the distant magnetotail of Jupiter during the ninth orbit.

To achieve the magnetospheric science objectives, the fields and particles instruments are required to operate in two modes: by collecting and downlinking data in real time and by recording data on the tape recorder and playing it back later in the orbit. There are a host of challenges the FPSG faces when implementing these operating modes: most of the magnetospheric data is collected in real time and must be integrated with other demands on the downlink signal. The engineering data, playback of recorded data, and the downlink of real-time science data must all be interleaved into the available telemetry. "It's fairly straightforward to integrate our own science tasks," said Spelts, "but there is a significant amount of interaction with other Project teams who also utilize real-time downlink resources. With the failure of Galileo's high-gain antenna, every downlink bit available becomes meaningful to all teams. It can be challenging to implement crucial science objectives while also staying within allocated spacecraft resources," Spelts continued. "Along with the ultraviolet spectrometers, we are the primary set of instruments on Galileo to routinely use both methods of data collection." A key function Spelts and other group members perform is to model the real-time data collection to ensure that the science data buffer on the spacecraft won't overflow. "If that happens," she warned, "data gets overwritten and we lose it."

Kim Spelts, FPSG Lead, began her career here at JPL in 1992, shortly after completing her BS in aerospace at the University of Colorado, Boulder. She can't remember when her lifelong interest in math and science began to focus on space, but the Viking landing on Mars and the first shuttle launches certainly made their contributions. Spelts came on Lab to work for the current EPD/HIC Team Chief, Neil Murphy—so it was fields and particles right from the start. In July 1994, when Project Galileo's reorganization took place, Spelts was assigned to the FPSG Lead position. An avid sportswoman with a special love of all things out-of-doors, Spelts completed the Sierra Club's rigorous Wilderness Travel Course last winter. The culmination of the course was a weekend snow camp in the Sierras, a real challenge. After hours, you'll find her on the softball field with JPL or Pasadena league teams. For a native Coloradoan, who departed the beautiful, green high-country wilderness at home for the brown chapparal of the San Gabriels, it's been a bit of a change (sigh!).

The FPSG has been together for over a year. Despite their differing backgrounds and responsibilities, Spelts described them as a tight-knit clan. "One thing we have in common is that we all like pizza and beer," Spelts noted. "Preferably between 9 and 11 in the morning," joked Bolton. ■

—Stephanie Nelson

The Probe Science Instruments

On the long ride to Jupiter, six instruments are resting inside the Probe, a mere 1.25 m in diameter and 0.86 m high. A July 12 JPL press release read the probe is "packed like an interplanetary paratrooper." And so it is. During this first and brief invasion of the Jovian atmosphere, these science instruments—the atmosphere structure instrument (ASI), helium abundance detector (HAD), lightning and radio emission detector and energetic particles instrument (LRD/EPI), nephelometer (NEP), net flux radiometer (NFR), and neutral mass spectrometer (NMS)—will capture diverse sets of data. The instrument science teams gathered at the July Probe Pre-Encounter Atmospheric Science Meeting to discuss their plans for analysis and interpretation of the anticipated new information on the composition, meteorology, and structure of the planet Jupiter; they also hope to gain evidence of how the solar system evolved.

In previous issues of *The Galileo Messenger*, four of the instruments—ASI, NEP, NFR, and NMS—have been discussed. Now we will examine the LRD/EPI and HAD.

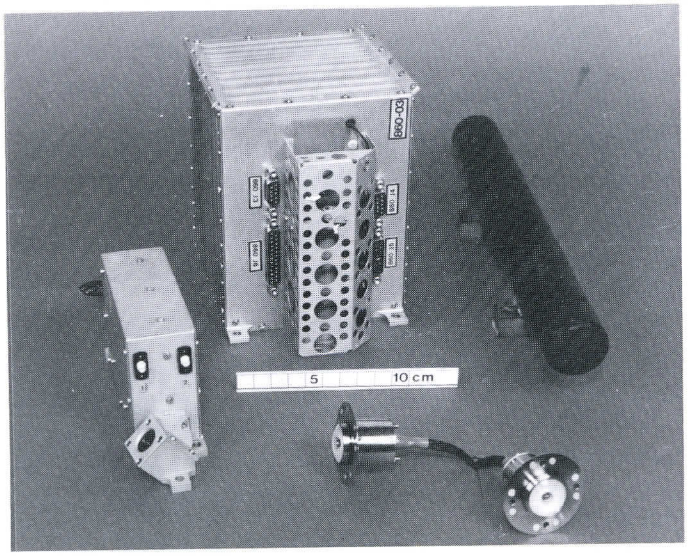
LRD/EPI, Two for One!

For the lightning and radio emissions detector and energetic particles instrument (LRD/EPI) investigation, two instruments share the electrical system that collects the LRD data—together with the scaling, data processing, and data formatting of the EPI. Louis J. Lanzerotti is the principal investigator (PI) for the LRD/EPI.

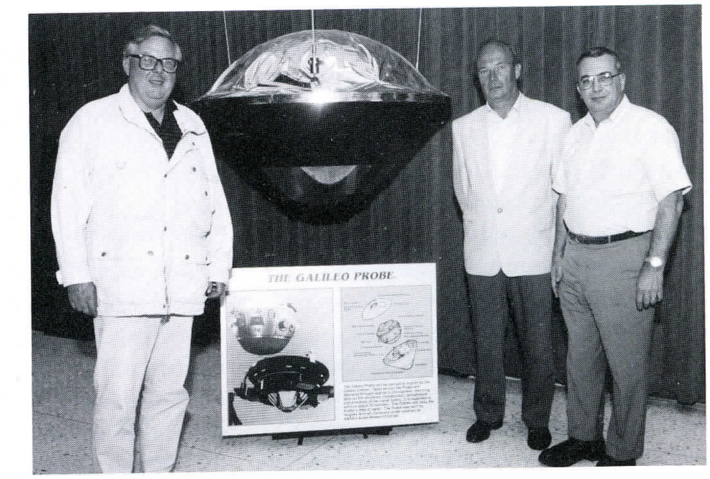
The Lightning and Radio Emissions Detector

Jupiter is aptly named for the Roman sky god, Light Bringer and Keeper of Thunderbolts. Prior to the Voyager 1 flyby of Jupiter, scientists speculated that lightning occurs in the planet's atmosphere as an energy source both for the nonthermal radio emissions from the planet (easily detectable from Earth) and for the production of certain nonequilibrium chemical species. Night-side photographs taken by Voyager apparently detected lightning, as did the plasma wave experiment that measured whistlers (signals that are probably caused by electrical discharges propagating in the magnetosphere). To help answer the questions—How is lightning generated? How often? How intense? What effect does it have on the chemistry and dynamics of the Jovian atmosphere?—in situ measurements were required.

The LRD is well equipped for the task; it was designed to take into account large uncertainties in the nature of possible Jovian lightning. The LRD hardware, funded and built by the Federal Republic of Germany, consists of three basic sensors: a radio frequency antenna and two photodiodes located behind fish-eye lenses. On the approach to Jupiter, it will take measurements at about 4, 3, 2, and 1 planetary radii above the cloud tops and then acquire data continuously during the parachute descent into the atmosphere. The radio frequency antenna will measure RF magnetic signals in the range from about 10 Hz to 100 kHz in three principal channels: a waveform analyzer for snapshots and statistics of lightning RF waveforms, a spectrum analyzer at three frequencies (3, 15, and 90 kHz), and a determination of the magnetic field/probe spin rate in one plane. There is also a single channel "superbolt" detection mode.



Lightning and Radio Emission Detector / Energetic Particles Instrument.



Standing beside the Probe model are (from left to right) Harald M. Fischer (EPI), Klaus Rinnert (LRD), and Louis J. Lanzerotti (LRD).

Meanwhile, back on Earth, the science team—PI Louis J. Lanzerotti, Co-PI Klaus Rinnert, Gunter Dehmel, Martin A. Uman, E. Philip Krider, and Fritz O. Gliem—has conducted numerous campaigns to study lightning on our planet and to "calibrate" a duplicate LRD. These results will enable a better interpretation of the Jovian data, and they have already contributed to our understanding of the ongoing electrical processes in Earth's atmosphere.

Lanzerotti graduated from Harvard with a PhD in applied engineering. He went directly to AT&T Bell Labs seeking a career with a future—the study of space. His work there on communications satellites and pure research on the ionosphere (and his association with the University of Florida) continues to be "where the action is."

Rinnert of the Max Planck-Institut für Aeronomie commented on the strong community that has developed among the German and American members of the LRD science team, representing the universities of Florida and Arizona and two German institutes at the University of Braunschweig. Close personal ties were also established with engineering colleagues at NASA Ames, JPL, Hughes, and Dornier Systems. "I have made good friends and have had much fun in doing this investigation. Besides the rewarding science and management part of it, there has been a nice person-to-person relationship."

The Energetic Particles Instrument

The EPI experiment will measure energetic particles during approach as the Probe passes through Jupiter's Van Allen radiation belts, located in the inner magnetosphere. The two-element telescope uses silicon surface barrier detectors to make omnidirectional measures of four species of particles—electrons, protons, alpha particles, and heavy ions (atomic number >2)—at high counting rates. The heat shield will be in place during the entire experiment. Particles must be very energetic to pierce it and be detected; electrons, the lightest, need the least energy and heavy ions need the most. Samples will be taken at 5, 4, and 3 planetary radii, then continuously from 2 radii to entry. A primary objective of the experiment is to determine the spatial and energy distributions of the energetic particles. At 5 planetary radii, the study will be in the vicinity of Io's plasma torus (thought to be a product of Io's volcanic eruptions). The torus plasma and associated magnetic field lines corotate with Jupiter overtaking Io (which is traveling 4 times slower). This condition induces a massive electrical field of about 400 kV across Io. (Pioneer 10 observed a peak in particle distribution of 460 keV.)

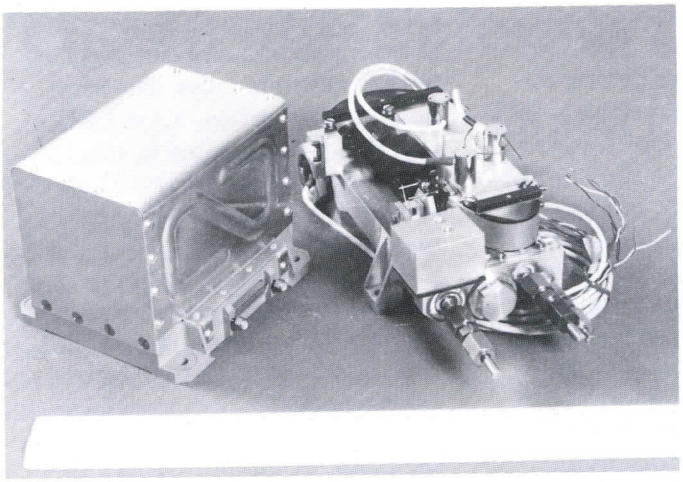
Four tiny moons circle inside the orbit of Io; two of these intercept the dust ring surrounding Jupiter at about 2 Jovian radii. Scientists believe that these moons and the dust ring influence the particle population between Io and the inner edge of Jupiter's radiation belt by sweeping up particles as they cross the moon's orbital path. The Probe's EPI will be the first to measure particles in this region where Jupiter's radiation belts are populated with relativistic (very fast, comparable with the speed of light) electrons that emit synchrotron radiation. In fact, observing Jupiter's synchrotron radiation has provided the only means of "seeing" into Jupiter's inner magnetosphere and is routinely monitored by the NASA/JPL Deep Space Network (DSN) radio telescopes. Data from the EPI will be compared with models based on the DSN and Pioneer observations. One recent theory concerning the synchrotron radiation suggests that an interaction between waves produced by atmospheric lightning and the relativistic electrons dictates the distribution of energetic particles in the radiation belts. The combined investigation of the LRD and EPI is well suited to test this concept, since the LRD will make some wave measurements in the magnetosphere.

Co-PI Harald M. Fischer, Institut für Reine und Angewandte Kernphysik, Universität Kiel, has been studying high energy particles in space since 1963; his first experiment flew on the German satellite DIAL (1969). Co-I John D. Mihalov, EPI team member at Ames, worked on energetic particle experiments for studies of the Van Allen radiation belts (1962–1965) and participated in the Pioneer flybys of Jupiter in 1973 and 1974. The EPI is a cooperative effort between the Ames Research Center and the Universität Kiel. Other science team members are Co-Is Jörg Bach, Fritz O. Gliem, Klaus Rinnert, Eckhard Pehlke, and Gerd Wibberenz.

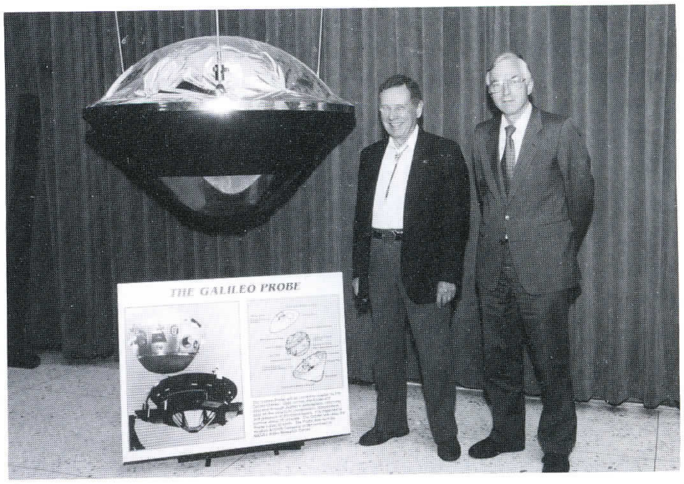
The HAD, Seeking A Key to Planet Formation

The purpose of the helium abundance detector (HAD) is to determine as accurately as possible the abundance ratio of helium to hydrogen in Jupiter's atmosphere. This ratio is also measured by the neutral mass spectrometer, but the helium abundance was judged important enough to justify the inclusion of a separate instrument. Moreover, the HAD has the ability to make the measurement to much higher accuracy. The uncertainty in the ratio is expected to be 0.0015, more than 10 times smaller than the best current number obtained from Voyager data.

In 1977, when the instruments were chosen, the weight of scientific opinion was that the helium abundance in the Jovian atmosphere is the same as that created in the Big Bang and present in the



The Helium Abundance Detector.



Standing beside the Probe model are (left to right) Donald Hunten and Ulf von Zahn (HAD).

solar nebula from which the Sun and the planets were formed. An accurate measurement, therefore, would tell us something about conditions at the instant of the Universe's creation; but later, the Voyager results for Saturn and Uranus, as well as more detailed knowledge of Jupiter and the Sun, have all suggested that processes in Jupiter could have modified the original ratio. The accurate measurement by the HAD is now seen as telling us about the origin and evolution of the planet itself.

After its arrival in the Jupiter atmosphere the HAD will begin to admit samples of Jupiter's atmosphere near the 2.5-bar level and will make repeated measurements as the pressure increases to about 10 bars. These measurements will become progressively more accurate; about 30 of them will be transmitted to the Orbiter. Analysis of these data will be based on the simulations of the descent made in the laboratory with a high-pressure chamber also capable of realistic simulations of the temperature profile.

The HAD was adapted from a tiny commercial instrument used to measure methane in coal mines and converted into a highly precise, space-qualified instrument for the helium measurement. The principle is to measure the refractive index of a sample of Jovian atmosphere by comparing it with a standard gas mixture carried from Earth. Technically it is a folded Jamin interferometer, working at a wavelength of 900 nm. The mass is 1.4 kg and it consumes 900 mW.

Along with this small size goes a small team of investigators: the PI is Professor Ulf von Zahn, formerly of Bonn Universität and now at the Institut für Atmosphärenphysik an der Universität Rostock, and the Co-I is Professor Donald Hunten of the University of Arizona. Hunten replaces Dr. Hans Hoffmann who left Bonn Universität to join the instrument contractor. Other important members of the team and their contributions have been W. Mett, who was responsible for radiation hardening of all the instrument subsystems; W. Schulte, who developed the apparatus for laboratory simulations of the instrument descent into the Jovian atmosphere; and H. Schuetze, who performed the calibration and environmental testing. Integration of the instrument into the spacecraft and systems tests were supported by H. Schuetze, K. Pelka, and G. Lehmacher. The interferometer part of the HAD instrument was developed by Carl Zeiss (Oberkochen, Germany), the other portion of the HAD by Messerschmitt–Boelkow–Blohm (Ottobrunn, Germany). ■

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sequence was one of the most critical and demanding we have executed to date. The sequence was two weeks long in order to accommodate several propulsion component tests (including the engine itself) before committing to the 5-minute ODM burn. The 400-N engine worked beautifully. The steady-state thrust is estimated to be 3 percent below the pre-flight predict—well within the 6 percent spec. Interestingly, this does not mean JOI will take 3 percent more propellant. The lower thrust could simply be due to a lower propellant flow rate. The amount of propellant required is determined by the specific impulse (Isp)—the impulse (force × time) per kg of propellant. Only the large propellant consumption of JOI gives us an opportunity to estimate the actual Isp. However, the observed lower thrust has been used to update our estimate of the *nominal* JOI burn time. The onboard fault protection will terminate the JOI burn at this time if certain faults have been detected; e.g., accelerometer failure or Attitude and Articulation Control Subsystem (AACS) power-on reset (POR). This nominal burn time is also used in setting the minimum and maximum burn time limits in the fault protection.

—see page 16

Up to Date

The following activity occurred over the last five months, April 7 through August 31, 1995. See related stories on Probe Release and ODM (see story, p. 4). The Orbiter is currently operating normally, spinning at about 3 rpm and is transmitting telemetry at 10 b/s. The Probe, healthy at the time of release, will not be heard from again until arrival at Jupiter.

Navigation

The planned TCM-24 for June was not needed because the Navigation Team found that TCM-23 had already achieved the required probe aim point. TCM-26 (ODM was TCM-25) fine-tuned the Orbiter's trajectory to the Io–Jupiter encounter aim point by removing the small trajectory errors of ODM (which had a very slight 1.2 percent underburn).

Galileo Mission Summary*

Distance from Earth	769,539,800 km (5.1 AU)
Distance from Sun	792,103,000 km (5.3 AU)
Heliocentric Speed	24,900 km/h
Distance from Jupiter	56,795,800 km (0.4 AU)
Round Trip Light Time	85 min., 38 s
System Power Margin	31 W
Spin Configuration	Quasi all-spin
Spin Rate/Sensor	2.89 rpm/Star Scanner
Spacecraft Attitude	Approximately 9 deg off-Sun (lagging) and 2 deg off-Earth (leading)
Downlink Telemetry Rate/Antenna	10 b/s (coded)/LGA-1
General Thermal Control	All temperatures within acceptable ranges
RPM Tank Pressures	All within acceptable ranges
Powered Science Instruments	PWS, PLS, EUV, UVS, EPD, MAG, HIC, and DDS
RTG Power Output	496 W
Probe	Cable cut and released
RRH	Receivers and oscillators powered off
CDM Loss Timer Setting	264 h
Time to Initiation	261 h
Real-Time Commands Sent	273,968

*All information is current as of August 31, 1995.

Dust Streams Continue

Additional memory readouts were performed during August to collect data on the greatest Jovian dust storm activity ever observed (it began July 28). The dust detector subsystem (DDS) instrument that collects data for the size and speed of these tiny particles has had impact rates ranging from a few hundred to almost 20,000 impacts per day. Compare this to the typical impact rate in space—one particle per 3-day period. The 3-week storm in April 1995 (reported in the May issue of *The Galileo Messenger*) collected a total of 2900 particles. Scientists look forward to learning the source of this tremendous dust stream activity after Galileo enters orbit around Jupiter.

Plasma Science Checkout

The plasma science instrument (PLS) has been checked out after an August 7 turn-on. The PLS is now configured for its measurements of the composition and the velocity distribution of plasma in the Io torus.

Relay Radio Antenna

On August 23, the relay radio antenna (RRA) was moved to the initial "elevation" pointing direction for probe relay on December 7 (the "azimuth" or "roll" direction will be established at about 4 hours before relay starts).

Gravity Wave Experiment

Data-taking for the second and final, long round-trip-light-time Gravity Wave Experiment (GWE) began May 20 and ended June 28. The experiment searched for low-frequency gravitational radiation-ripples in the curvature of space-time that are predicted by Einstein's general relativity. The GWE is motivated both as a test of physical law (gravity waves are a prediction of general relativity, but have not yet been directly detected) and as a potential new window for observational astronomy. The GWE used the Earth and Galileo as test masses, with their relative velocity continuously measured by Deep Space Network Doppler tracking. The observations required that the spacecraft be near opposition, the Earth–Galileo distance be large, and Galileo be in interplanetary space. These conditions were required to minimize the detrimental effects of the interplanetary plasma on the radio signal. A gravitational wave incident on the Earth–spacecraft system will cause three small perturbations in the Doppler frequency. While it is thought that gravitational waves will be rare at the sensitivity level set by the Galileo radio system, analysis of the GWE data is underway, and even a negative result will help to constrain models of gravity wave phenomena.

Key Uplink Planning Activities

The Project approved the final updates to the sequences that cover spacecraft activities from October 9, 1995 to January 3, 1996, the so-called Jupiter Approach and the Jupiter Encounter time periods. Special testing of the critical engineering sequence, called Relay/JOI will be performed on the spacecraft testbed in the period from September 6 through October 11, 1995. This sequence is designed to ensure that, even in the face of faults, Galileo will acquire the probe data and get into orbit around Jupiter.

Telecommunications/ Ground System

Several tests of the Block V receiver (BVR) were successfully performed over DSS 14 and DSS 43 in June in preparation for their first operational support of Galileo at probe release. Telemetry rates of 8, 10, and 16 b/s were received and processed, as was two-way Doppler data for navigation.

Anomaly Status

Analysis of data received since the July 27 ODM shows that one of the two check valves in the helium pressurization system apparently remains open. The purpose of these valves (one on the fuel side and one on the oxidizer side of the propellant system) is to limit the amount of propellant vapor that can flow upstream, potentially condense, subsequently react, and in a possible, but very unlikely scenario, damage the propellant feed system. Project engineers plan to manage the propellant temperatures and pressures to minimize the possibility of reaction. Even without this additional propellant temperature and pressure management, the propulsion system design makes the potential for any harmful interaction of the propellants very low. No impact is expected on planned maneuvers or on the mission as a whole. ■

Meet the RSSG (Continued)

In our May 1995 issue, you met the Remote Sensing Science Group (RSSG). Let's look a bit closer at the activities of the teams that support the four remote-sensing science instruments mounted on Galileo's scan platform: the solid-state imaging (SSI) subsystem, the near-infrared mapping spectrometer (NIMS), the photopolarimeter/ radiometer (PPR), and the ultraviolet spectrometer (UVS), plus a fifth instrument, the extreme ultraviolet (EUV) spectrometer mounted on the spinning part of the Orbiter.

Picture Taking— At a Distance

On October 11, the SSI camera will take a color image of the half-lit Jupiter. The SSI Team Chief, Ken Klaasen, and Science Coordinators Herb Breneman,Todd Jones, Jim Kaufman, Kari Magee, and Dave Senske are now focusing on the sequences for Orbits 7 and 8 of Jupiter. After a close-up view of Io at arrival, Orbits 1 and 2 will focus attention on Ganymede, mixing global and high-resolution (1 km or better) images of selected craters and other land features seen by Voyager. Global views will provide the context for high-resolution shots, a combination that can lead us to an understanding of the history of geologic events. Images in color will define boundaries between surface features whose rocks and ice have differing chemical composition. The SSI will gather similar data on Callisto on Orbit 3 and Europa during Orbits 4 and 6. Other sequences will include monitoring volcanic activity on Io, noting changes from Voyager images; the study of the Jovian inner small satellites and Jupiter's ring; and a close-up inspection of Jupiter itself. While too near for global views, the team can "watch" from close range the plumes, hot spots, and other atmospheric features previously spotted from Earth and Voyager. Their data will also supplement the Probe's data on the Jovian atmosphere.

Besides planning sequences for each of the 10 orbits, the SSI team is busy assessing the effect of the new data compression software that accommodates the low-gain antenna requirements. To do this, they exercise the compression software, using Voyager and Galileo cruise imaging data, and then compare it with precompression results. The team is also studying the effects of radiation on their camera during passage through Earth's radiation belt (Earth-2 approach 1992). Models developed will enable them to counter image noise from Jupiter's strong radiation belt.

They Saw Venus From the Night Side

Infrared observations of the Jovian atmosphere and Galilean satellites are being implemented by the NIMS Team Chief, Bill Smythe, and Science Coordinators

Kevin Baines, Elias Barbinis, Paul Herrera, John Hui, Rosaly Lopes–Gautier, Frank Leader, Adriana Ocampo, and Marcia Segura. Their first-ever glimpse of the surface features of Venus in the infrared occurred in 1990 during the Galileo Venus flyby, and their near–infrared mapping spectrometer, NIMS, obtained exciting results from the Shoemaker–Levy impact.

Now the NIMS team is eager for the December arrival of Galileo at Jupiter. At that time, the Io flyby will offer them the opportunity to investigate the satellite's volcanic activity at close range. From the many colors collected by NIMS, we can learn the average composition of minerals and ices in small areas. For Io, NIMS will map the distribution of sulfur dioxide and the temperatures of volcanos. The composition of the lineated areas on Europa, the polar hood on Ganymede, and the large impact structures on Callisto will be prime targets. Measurements of the satellite compositions and the temperature and composition of swirling clouds and hot spots of Jupiter will continue throughout the tour.

Taking Their Temperature

Terry Martin, Science Coordinator for the Photopolarimeter/Radiometer (PPR) instrument, and his assistants, Leslie Tamppari and Karen McBride, are planning the sequences needed to collect thermal and reflected radiation data about satellite surfaces and atmospheric properties. The PPR "takes the temperature" of clouds and gases in the upper Jovian troposphere to develop a thermal radiation profile, using five spectral bands between 15 and 100 μm. The PPR data will tell us the temperature of the Galilean satellites and the structure of Jupiter's atmosphere—the physical nature of the planet's clouds and gases and how they are layered. We will learn about the texture and structure of the satellite surfaces. Are they dusty or icy? Similar to a light meter (you may have a simple one on your camera), the PPR measures the reflected sunlight in ten spectral channels between 410 and 945 nm.

The PPR instrument had its own chance to shine when it detected light flashes during the fragment impacts of the S–L9 event. Its fixed stare at target Jupiter required no distracting platform movement. Data were collected directly into the spacecraft computer and then sent to the ground via the next memory readout (MRO). During that exciting week of comet watching in July, 1994 data delivery was overnight. Other instruments were forced to tape record their data and wait weeks or months for playback. The team reported its findings immediately on a special World Wide Web exploder and in *Science* magazine this last July.

Viewing the Unseen Spectra

UVS/EUV Team Chief, Joe Ajello, and Science Coordinators John Aiello, Steve Edberg, Keith Naviaux, and Kent Tobiska are planning their sequences to observe the UV spectra of the Jovian planetary system and the magnetospheric plasma. Ninety percent of the data will enter the real-time telemetry stream through the orbiter central computer (CDS) and be downlinked at a rate of either one or two spectra per hour; the rest will be captured on tape. Since the UVS can observe the entire ultraviolet-near-visible spectrum from 115 to 432 nm, it will be able to detect emission, absorption, and scattering features in the unexplored 170- to 432-nm wavelength region. The UVS team is also responsible for the EUV spectrometer. This flight-spare Voyager UVS instrument was procured during the Galileo redesign required by the Challenger loss. The EUV will be employed to follow up on Voyager discoveries. It will observe sulphur and ion emissions from the Io torus and atomic hydrogen auroral and airglow emissions from Jupiter. Joe has been busy analyzing previous interplanetary Lyman α and He (58.4 nm) emission sprectra data; this cruise information is useful in predicting instrument performance on the coming tour.

The Feature Track Campaign

Kent Tobiska, UVS Co-Investigator and Science Coordinator for ultraviolet atmospheric auroral studies, described the campaign to efficiently collect data for a particular feature, such as the Red Spot. Kent is a member of the Atmosphere Working Group (AWG) (one of three such groups) formed to work in concert on a particular piece of science. The AWG unites the instrument teams to integrate the capabilities of four of the remote-sensing science instruments by instructing the NIMS, SSI, PPR, and UVS to collect data on the same feature. The UVS, for example, will take data on a feature at many wavelengths between 115 and 300 nm. These observations are simultaneous with the SSI images of the same feature. This campaign technique proved its value during the recent comet Shoemaker–Levy 9 impact event. Emissions observed by the UVS, combined with those by the PPR and NIMS made it possible for the AWG to determine that the temperature of the comet's G fragment fireball is a torrid 7500 K! ■

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Detailed analysis of the telemetry data following ODM shows that one of the two helium pressurant check valves is not closed. The purpose of these valves—one on the fuel side and one on the oxidizer side of the propellant system—is to limit the amount of propellant vapor that can flow upstream and potentially mingle in the pressurization system. The Galileo propulsion system design makes the potential for any harmful interaction of these vapors extremely low even with an open checkvalve. Nonetheless, we are now holding the propellant temperature constant to minimize any vapor transport.

The Probe Release and ODM are very publicly visible events. What is not visible is the tremendous amount of careful planning—especially the contingency planning—that goes into these events. We re-visited all aspects of Probe Release this past year. And for well over a year, we have been working intensely with our colleagues at DARA and DASA (designers and builders of Galileo's propulsion system), studying every possible contingency and performing further testing at DASA on flight identical hardware in order to have the very best plan for ODM and JOI for all plausible contingencies. Our contingency plans for the Release and ODM were outstanding. They were the product of the utmost careful thought and dedication.

It has been suggested that "John Casani's intergalactic ghoul" monitors our activities closely and will not visit upon us any contingency that we are prepared for. In any case, we must do our best to be prepared for those reasonably plausible contingencies that could threaten our major objectives.

The Project Galileo and Deep Space Network teams continue to do a truly outstanding job operating the Galileo mission.

Preparations for Jupiter are also not publicly visible and these have made tremendous progress over the summer. The Project has been absolutely relentless in making the Relay/JOI Critical Engineering Sequence (CES) as reliable and robust as possible. The CES is now finalized and entering a rigorous final testing program on the Spacecraft Testbed. We are satisfied that we now have the best possible CES!

Completion of the Orbital Operations Flight Software (Phase 2) continued to be a great challenge. In spite of Herculean efforts we didn't complete "flyable" Command and Data Subsystem (CDS) flight software (FSW) in July. Fortunately, those continuing efforts did deliver the intended final CDS FSW to the Project for System Testing this month. The final testing of this FSW is now proceeding in parallel with the design of the Phase 2 Inflight Loading process with little, but adequate, schedule margin to begin the uplink to the spacecraft on schedule in March 1996. It is crucial that Phase 2 be installed then so that the arrival Orbiter science observations can be played back from the tape recorder before the July 4, 1996, Ganymede 1 encounter.

Five of the ten orbital tour encounter sequences are now completed and ready for translation to uplink command files, pending only some final updates shortly before transmission to the spacecraft.

In August, the Orbiter's Relay Radio Antenna (RRA) was slewed to its initial Relay cone angle where it will remain for the first 32 minutes of the Probe Relay Link. The four stepping slews that will be done in the remaining 43 minutes of the Link were nicely incorporated in this deployment to verify their performance. Cone angle is analogous to elevation angle. The azimuth or clock angle of the RRA is controlled by positioning the stator (despun section). This month a test is being run on the spacecraft to demonstrate the new capability to control the stator using only the star Canopus as a roll reference, which is part of the autonomous fault protection to be invoked if a gyro problem occurs during relay.

Galileo's Jupiter approach observation sequences begin October 9th. On October 11th Galileo will take a color image of Jupiter, containing the Galilean satellites Io and Ganymede. Since the Phase 2 capabilities won't be onboard yet, it will take nearly a month to return this color image. We hope to present it early in November. It will be the only image returned until the Phase 2 software is running on the spacecraft in May 1996.

Are we there yet? Almost! ■

— Bill O'Neil

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Last Issue Before Arrival!

If you are wondering about our schedule . . . *The Galileo Messenger* is published on an event-driven basis. The next issue? February.

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

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The Galileo Messenger

Issue 43 May 1997

From the Project Manager

Project Galileo continues to perform superbly. Yes, *Project* Galileo—not just our magnificent spacecraft, but equally important, the hundreds of people on the ground that make it work. The people of the Project Team, including our German propulsion colleagues here and there, Galileo scientists worldwide, the people in the JPL Multimission Ground Systems operations, and those in the Deep Space Network at Pasadena and the tracking sites in California, Spain, and Australia, including the folks at Australia's Parkes 64-m antenna. The ensemble of all the things that must be done on a continuing basis to "operate" Galileo is truly mind-boggling. The lead time ranges from years to at times only minutes. It is an enormous plan of steadily increasing detail as a set of observations or a downlink nears. And, quite often, contingencies require the most insightful troubleshooting and recovery actions. It is a global team of the first magnitude.

Since the last *Messenger* just 2months ago, the Ganymede-7 and Ganymede-8 encounters have been successfully performed—Galileo is now 7 for 7 orbital tour satellite encounters, less than 1 year since starting with Ganymede-1 in June1996. Once again these recent encounters were punctuated with skillful real-time anomaly recoveries. Less than a day before Ganymede-7 closest approach,

—see page 4

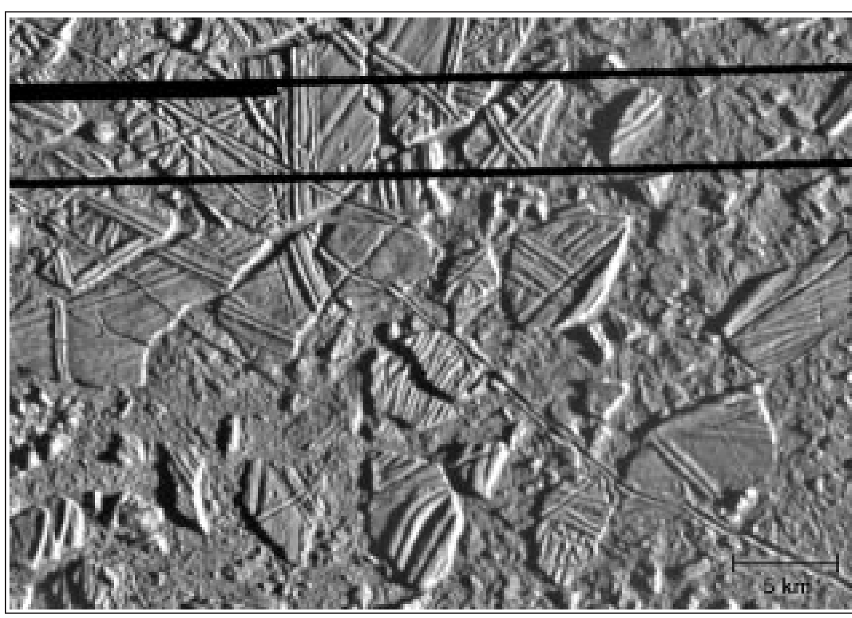
An Ocean Discovered:
Europa Surrenders Her Secrets

Sixteen months into the Jovian system tour, public interest has shifted increasingly towards Europa—the newest superstar on the celestial stage. Prospects for subsurface water, and with it, life, have never looked brighter.

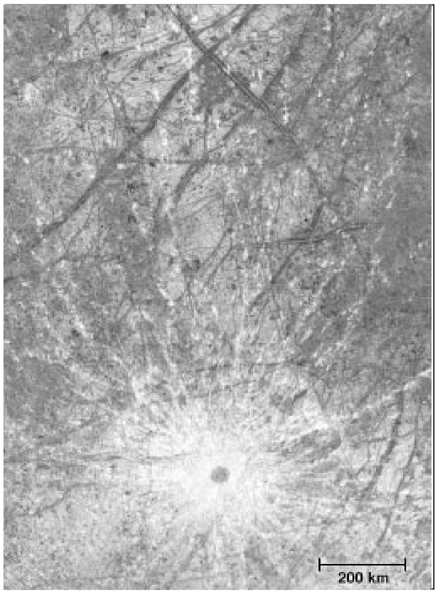
Floating Icebergs?

When the Galileo Orbiter swooped within 587 km (363 mi.) of Europa's icy crust, on the E6 pass of February 20, its Solid-State Imaging (SSI) camera captured an array of breathtaking, mind-blowing images. The panel of eight investigators (moderated by David Seidel) that reviewed the E6 science on April 9 at JPL's von Kármán Auditorium was certainly the most diverse Galileo group, and perhaps the most excited, to face the international press.

Michael Carr of the U.S. Geological Survey was not new to the crowds at von Kármán, but his previous appearance had been to discuss hidden water on Mars. Now, in his first appearance on a Galileo panel, he spoke of hidden water on Europa. Seated below a large, full-color image of the Europan surface, he maintained Galileo had discovered the "smoking gun" that indicates the signature of a subsurface ocean in the place where nature marked the



Europa's ridged crust, broken into "icebergs" that have slid, turned, and tipped.



Low-resolution image of the trailing hemisphere. Note patches of dark and light terrain.

spot with a large “X.” The image above, centered over the trailing hemisphere, showed the bright crater Pwyll to the south, and, near the northern edge, two dark-red triple bands, one crossing the other at a right angle—the “X.” And just south of the intersection, an irregular dark-red patch, maybe 50-km wide. This was the patch from which Robert Sullivan, of Arizona State University, had introduced (only minutes before) the celebrated image of the Europan icebergs, floating in their now-frozen sea (see p. 1). Carr was visibly impressed with the way these enormous, 3-to-6-km-wide blocks, scarred with ridges, were tipped and rotated. This motion, he explained, could not be accounted for by wind or slope, but could be caused only by the traction of currents in a liquid medium.

Paul Geissler from the University of Arizona, and also new to the panel, concurred. The tilted bergs, he explained, showed just how thin the surface here was—perhaps only 1-or 2-km thick! [Thin indeed compared to a 100-km (60 mi.) deep ocean.] Geissler also explained that convection in solid ice (suspected on Ganymede) could not account for all the observed movement. And the lack of any feature higher or deeper than a few hundred meters would be consistent with a 1- or 2-km layer of floating ice [remember, icebergs are 90 percent below the surface].

Max Coon of the Northwest Research Association displayed a picture of pack ice in the open water of the Earth’s own Arctic Ocean for comparison. Such floes, he explained, frozen in a winter sea, would resemble Europa’s bergs even more closely. Open water on Europa would boil and freeze at the same time; the rapid freezing would seal in further loss; the water vapor released into space would settle as snow and help color the whitest, brightest surface in the solar system.

Diverse Features

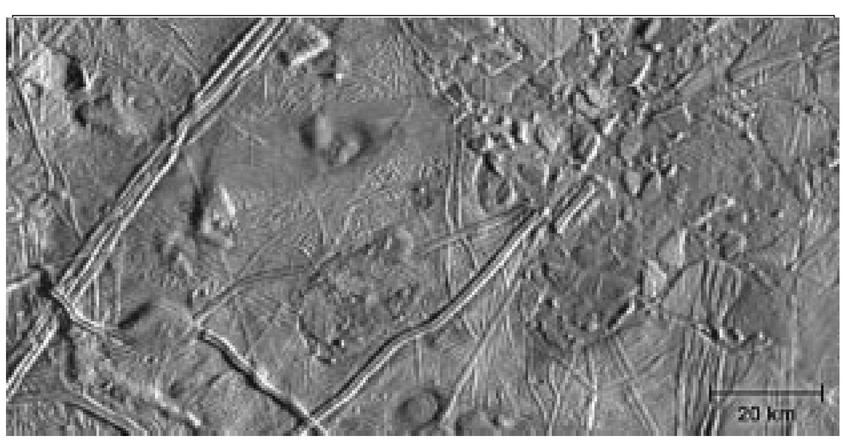
Larger areas of the surface show a bewildering complexity of features (see below). Here, the icebergs appear to be frozen in an area surrounded by sound, unbroken, grooved crust. Yet portions of this crust also show smaller areas within which the surface seems to have melted, then refrozen as a choppy, rubbly patch that obliterates the older pattern of ridges and grooves.

Even stranger, some areas look as smooth and flat as skating ponds. Sullivan’s introduction included the image from the E4 pass (see p. 3, top left) that showed both a sharp-edged, jumbled patch and a smooth, flooded area. These two features are separated by only 5 km, yet the older, eastern one shows what may have been the sudden collapse of a 4-km-wide section of crust that refroze as a mass of broken, floating chunks; the younger, western one shows what may have been the gradual sinking of an equally wide area and a gentle flooding from below.

How Old a Surface?

Close up, neither of these features shows even the slightest resemblance to impact craters, but from a distance they appear dark against the whiter, ridged crust. As “freckles,” they were considered impact craters and included in preliminary counts. Clark Chapman, of the Southwest Research Institute, noted that this confusion resulted in crater counts about 100 times greater than now observed! This means a surface proportionately much younger, maybe even less than a million years. This is a geological eye blink, and Chapman credited only the Earth and Io with more active crusts.

Michael Carr, echoing some of the passion in the surface-dating debate, pointed out that the cratering rate in the Jovian neighborhood is much less well known than the rate around the Earth and the surface could be much older. Given such uncertainty, Clark Chapman thought it might even be younger, while Torrence Johnson, Project Scientist from JPL, felt that even much older than a million years would still be geologically young.



A variety of features are visible in this blowup of an area just below the X in the image at the top of this page.

Closeup with melt features.

The Case for an Ocean—and Life!

The evidence for a deep ocean, then as Richard Terrile from JPL, suggested, is "strong." If, he added, it underlies the whole surface, then the Europan ocean would contain more water than exists in all the oceans of the Earth! As best we can tell, life on Earth appeared within 700 million years of its formation, 4.6 billion years ago. From its beginning, the Europan environment with abundant water, rich in dissolved minerals and organics, would be suitable for the origin of life. As old as the Earth, this moon has had time for life to evolve.

John Delaney, an oceanographer from the University of Washington, the first of that discipline at a Galileo press conference, shared some of his passion for exploring the Europan ocean and discovering life. He noted that about the time the Voyagers were downlinking the first pictures of Europa's flat, icy crust, deep-diving oceanographers were discovering the first volcanic-vent communities on the Eastern Pacific sea floor.

Delaney could confidently report that today, wherever sea-floor volcanism is found, so will be rich and diverse life. This suggests a new biological paradigm—a new way to view life: wherever you find volcanic activity and liquid water, even *within* rock, you will find life.

The panel speculated on possible follow-on missions to Europa—orbiters to map the sub-surface water, "cryobot" penetrators to reach the hidden sea, and "hydrobot" submersibles to plumb its sunless depths.

As Project Galileo continues to study Europa's mysteries, we discover even more. Europa has proved to be a far more interesting place than ever imagined. And we've only begun.❖

—Larry Palkovic

Meet the Outreach Team

Getting the Word Out

"The part of my job that I like most is translating science-ese into everyday words people understand. It's gratifying to see so many people eager to learn about our new discoveries," said Leslie Lowes, Lead for Galileo's Outreach Team that conveys new findings from Galileo to educators and the public worldwide. Leslie coordinates the efforts of the Outreach Team and creates the printed materials (including brochures, posters, and slide sets featuring Galileo's images) that inform the public and educators. Requests come in from people around the globe.

Team members include Jo Pitesky, Ron Baalke, Rebecca Westbrook, and Aimee Martinez. Jo Pitesky shapes Galileo's scientific data into accessible classroom exercises and writes material for the Galileo Project home page, <http://www.jpl.nasa.gov/galileo>, for which the Galileo Outreach Web Page Development Team won a JPL 1997 Award for Excellence last month. Jo also answers questions like, Why aren't all the science data made public as soon as they're received? The data requires considerable processing before it can be interpreted. "We're grateful that the scientists release so many of these important photos and other data after having only a very short time to analyze them," said Jo. She manages other Internet educational events on the Online from Jupiter home page <http://quest.arc.nasa.gov/project/jupiter.html>, where students may read science team member biographies and daily activity journals. "Viewing these entries lets young people live the mission through the Internet," said Jo.

The Outreach Team: (from left, standing) Ron Baalke, Rebecca Westbrook, Aimee Martinez; (seated) Leslie Lowes and Jo Pitesky surround their favorite planet.

Jo and Ron Baalke maintain the Galileo Web site; "hits" by daily visitors average over 100,000, depending on breaking news, such as last month's Europa news conference (see story, p. 1). Ron also maintains the Galileo electronic mailing list of over 5000 subscribers. The site offers new Galileo images daily, answers questions via e-mail, and features

chat groups where several hundred people log in, many with questions for the Project and Science Teams.

Rebecca Westbrook, a co-op student from the University of Washington, is coordinating the production of the Galileo informational CD-ROM due out this summer. “Rebecca has been producing our popular, on- and off-Lab teacher workshops that demonstrate how the mission is run,” said Leslie. “Her tenure at JPL is over in June, and we’re sad to lose her. But we’re proud to be bringing in Priscilla Beckman, a science teacher at Crescenta Valley High School, to coordinate the workshops.”

Aimee Martinez, a student at Pasadena City College working part time, provides critical, skilled computer and clerical assistance.

Others support the Team in many ways. Project Scientist Torrence Johnson often is one of the first to tell Galileo’s story to the media as it unfolds. Elizabeth M. Alvarez del Castillo coordinates outreach for the Solid-State Imaging (SSI) Team that provides the bulk of the image-per-day capability for our Web page and designs classroom activities around these images from Galileo’s camera. Maynard Hine, who designs displays for the group (and a new touring exhibit), worked with Leslie to produce the three-fold, “Travels of Galileo.” Ed Hirst writes the “This Week on Galileo” story for our Home Page and keeps us current on mission planning activities. Tiffany Chiu is responsible for the product inventory. Bill Hoffman supports the art work needed. Valerie Pickett answers individual requests for Galileo material. And Jan Ludwinski, Chief, Mission Planning Office (that includes the outreach function), acts as consultant.

Leslie just returned from conducting a seminar at the National Science Teachers Association Conference in New Orleans. In her free time, she sings in three choirs and loves to ride her bike with friends; twice she has biked from Pasadena to San Diego.❖

— Tom Wilson

PROJECT MANAGER from page 1

celestial reference was lost when the bright body protection “blocked” one of the two stars being used. The problem was diagnosed, and a different star was substituted by real-time commanding just hours before closest approach. Two days before Ganymede-8, it was discovered that the inboard Magnetometer sensor was opposite the planned orientation (flip), and the corresponding transformation matrix had to be real-time commanded several times throughout the encounter.

This past week, the Project Science Group (PSG) held its quarterly meeting at JPL. Excellent progress was made in planning the science observations for the Galileo Europa Mission (GEM). One day of these PSG meetings is now devoted to reports by the investigators of their latest science results. These reports show the tremendous breadth, quality, and quantity of science Galileo is providing. Publicly, the pictures from Galileo’s Solid-State Imaging (SSI) camera always steal the show, just as in this issue of *The Messenger*, highlighting the “mind-boggling” Europan icebergs. There are ten other instruments on the Galileo Orbiter and two radio science investigations, all of which are providing excellent scientific results. We continue to struggle to find better ways to communicate the excitement and importance of the non-imaging data to the general public. Just a few examples: the Radio Science Celestial Mechanics Investigation “senses” the internal structure of the satellites and has discovered that Io, Europa, and Ganymede all have dense cores while Callisto is uniform throughout. The fields and particles instruments have discovered that Ganymede is magnetized, possibly Io as well, Callisto definitely not, and Europa yet to be determined. And they continue to map the composition and dynamics of Jupiter’s lethal magnetosphere—the largest volume in our solar system at one-hundred times the volume of the Sun. This summer between the Callisto-9 and Callisto-10 encounters, Galileo carries these instruments 10million kilometers deep into the magnetotail opposite the Sun to achieve one of Galileo’s most important science objectives.

The Near-Infrared Mapping Spectrometer (NIMS) is providing excellent data to study the surface chemistry of the satellites, including volcanic hotspots on Io, and is, in effect, doing water sounding over the Jupiter globe—to mention just some of its contributions. The water sounding is providing important information about one of the major puzzles from the Probe observations—the apparent underabundance of water. NIMS data are showing that local water abundance below the clouds varies widely across the planet, suggesting that, indeed, Jupiter weather dried out the region where the Probe descended.

By the way, the original, official Project Plan for Galileo published in 1978 had *NO* encounters of Europa or Io, and the encounters of Ganymede and Callisto were all at or above a 1000-km altitude. Galileo has already encountered all four Galilean satellites typically at lower altitudes with a low of 261km at Ganymede-2.

Galileo is indeed superbly fulfilling its objectives at Jupiter.❖

— Bill O’Neil

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The Galileo Messenger

Issue 44 **July 1997**

From the Project Manager

First of all, all of us on Project Galileo heartily salute our colleagues on the Mars Pathfinder Project for their spectacular success. As we watched them on July 4th, we certainly could directly relate to their anxieties and ecstasy. Seeing signal from the Pathfinder Lander after landing was the perfect analogy to our Galileo Orbiter signaling to us that it was seeing the Atmospheric Probe signal after entry. And comparisons are natural and countless. Upon reflection, I find it particularly striking that the flight time of Mars Pathfinder from Earth to Mars was almost exactly the same seven months as Galileo's first orbital flight around Jupiter: December 7th vs. 4th to June 27th vs. July 4th—and our arrival at Ganymede-1 would have been July 4th (1996), except that our adaptive navigation strategy resulted in the one-week advance in Ganymede arrival.

It reminds us of the vastness of the Jupiter System our Galileo Orbiter is exploring. It is indeed the "miniature" solar system we refer to, consisting of 16 known natural satellites. And our flights from one of the major satellites (the Galileans: Io, Europa, Ganymede, and Callisto) to the next are completely analogous to interplanetary flights in the inner solar system—the gravity-assist at

—see page 4

Probe Mystery Solved:

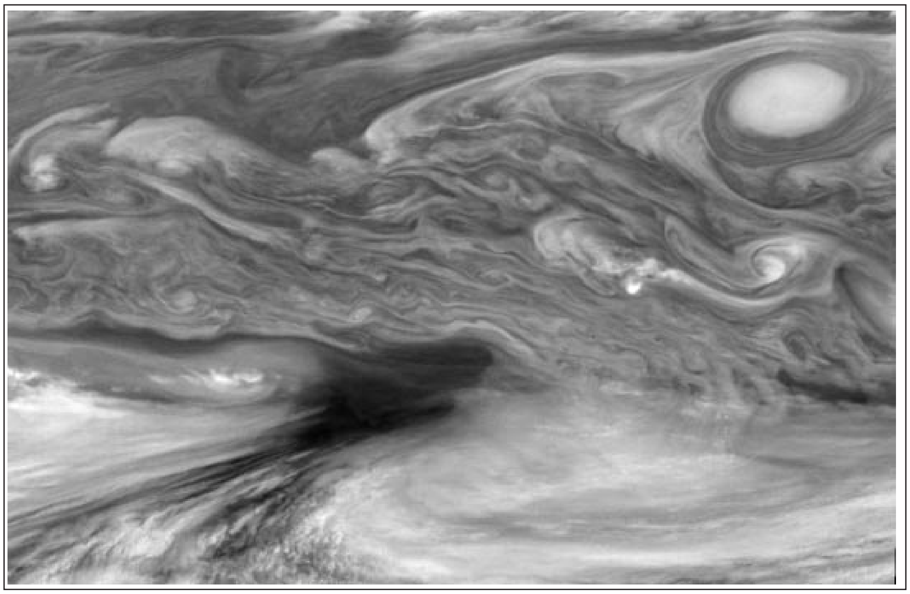
Jupiter as Wet (and Dry) as Earth

Jupiter Atmospheric Science Panel, from left: Dave Seidel [Moderator; JPL], Andrew Ingersoll [Interdisciplinary Scientist (IDS), Solid-State Imaging (SSI) Team; Caltech], Tobias Owen [IDS and Probe Neutral Mass Spectrometer (NMS) Team; University of Hawaii], Glenn Orton [IDS and SSI, Photopolarimeter/ Radiometer (PPR), Probe Nephelometer (NEP) Teams; JPL], Robert Carlson [Principal Investigator (PI), Near-Infrared Mapping Spectrometer Team (NIMS); JPL], Ashwin Vasavada [SSI Team Affiliate; Caltech].

Questions And Answers

The unexpected dryness at its entry site was one of the Galileo Probe Mission's more perplexing mysteries (see "The Probe Story: Secrets and Surprises from Jupiter," *The Galileo Messenger*, Issue 38, April 1996). Was Jupiter globally dry? Was the water everyone expected to see somehow locked in its interior? Or was the weather on Jupiter as varied (and interesting) as on Earth? These were the questions Andy Ingersoll of Caltech and the Galileo Science Team raised at the Galileo Press Conference at the Jet Propulsion Laboratory on June 5 in von Kármán Auditorium. The panel of researchers (pictured above) was most pleased to report that the latter model of a planet with a richly complex and dynamic weather system was the correct one.

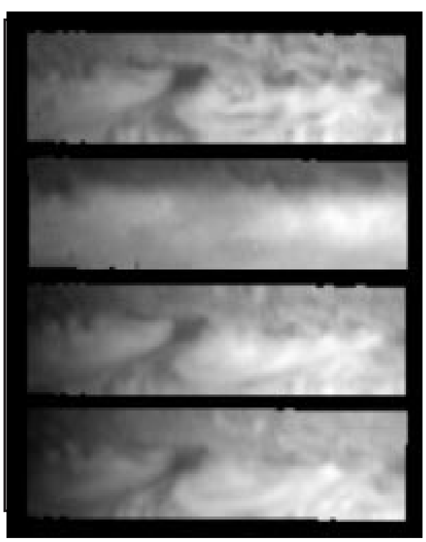
—see page 2



Photomosaic of SSI images showing a 34,000-km-wide swath from the Jovian equatorial region. The dark area is a hot spot—similar to the one that swallowed the Probe—where the air is drawn down to the interior; circulation is counter-clockwise. Bright, white areas are columns of rising air, spinning clockwise and topped by clouds.

Probing Hot Spots

Since the Probe entered at a hot spot, the Galileo Science Team selected other such areas to investigate—like the hot-spot area shown in the SSI image above and in the NIMS view below. Analysis from the output of the SSI (visible light) camera, NIMS, PPR, and the Ultra-violet and Extreme Ultra-violet Spectrometers (UVS/EUV) proved very fruitful.



NIMS swaths showing the same hot spot as in the SSI image above, but in four different IR wavelengths: 2.74, 1.99, 1.61, and 0.76 µm (top to bottom). The 1.99-µm wavelength senses the upper clouds and haze; other wave-lengths probe deeper in the atmosphere.

Different atmospheric constituents (both chemical composition and particle size) react differently to different wavelengths of electromagnetic radiation. The NIMS image scanned the same hot spot as SSI, but in many different infrared (IR) wavelengths. The series of such images yields what amounts to a three-dimensional picture of the atmosphere, because different constituents are concentrated at different levels.

Because water absorbs IR, NIMS can generate water maps. Those that NIMS PI Bob Carlson displayed showed both the rare, very dry areas (like the Probe entry zone), with about 1% relative humidity, and more common water-saturated, very wet and likely rainy areas.

Understanding Jovian Weather

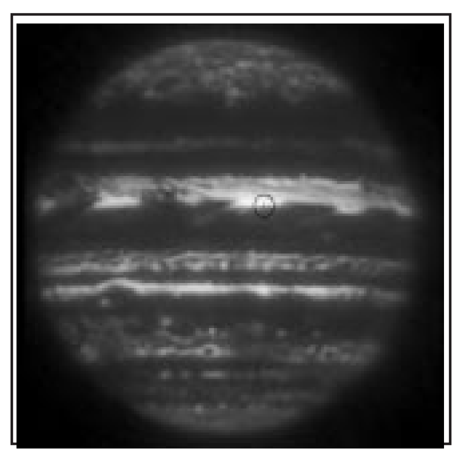
Fundamentally, Jovian weather resembles Earth's, but Jupiter has no solid surface. Its weather is driven by heat (as on Earth), but the source is different; instead of the Sun warming a surface, and the surface heating the air above it, heat in Jupiter is from deep down (as indicated by Probe data).

The atmospheric processes that Toby Owen of the Probe NMS Team described resemble Earth's: a rising column of heated Jovian air (mostly a hydrogen–helium mix) cools with expansion as it rises, then condenses out clouds (water droplets low, ice crystals higher) and rain (or snow). But on Jupiter, the rising air also condenses out hydrogen sulfide as a higher, colored (but wispier) cloud layer and ammonia as the highest cloud layer. Seen from Galileo, the region of updrafts is cloud-topped, and very bright. Above the clouds, the air at the top is very cold, very clear, and dry of all volatiles (which condensed out below).

What Goes Up . . . Comes Down

The high, clear air rolls outward, sinks, compresses, and heats up. Nothing condenses on the way down—the warming air is dry and soaks up any volatiles, so the region of subsiding air is clear. These areas are dark in visible light, but bright in the infrared. The videos that Glenn Orton of the PPR and Probe NEP Teams brought from NASA's 3-m IR telescope in Hawaii showed Jupiter glowing through its hot spots like a colossal cosmic jack-o-lantern (see below).

While the Jovian atmosphere has no real bottom, far below the underside of the water cloud deck is a layer of mixing, where the torrid air is enriched with heavier elements.



Jupiter with Probe entry site (circled). IR image taken at 4.85 µm from NASA's IRTF with the NSFCAM instrument, 11/21/95.

The global atmosphere circulates on a gargantuan scale (almost 500,000 km about the equator): regions of rising air spread around the planet as a system of bright, latitudinal *zones*. Regions of sinking air spread around the planet as a system of dark *belts*, studded with even darker hot spots, clear all the way down to the dark, hot mixing level.

The boundary between the belts and zones is very turbulent; images of these areas through time show wind strength and direction as clouds are blown about. Ashwin Vasavada of Caltech showed such videos of thunderheads moving toward a dark hot spot. His narration of an animated flight between cloud decks around a hot spot was especially interesting.

It was into such a dark, dry hot spot that the Galileo Probe dropped in December 1995. While the area around it was as dry as any desert on Earth, the distant lightning it detected hinted that wetter, stormier weather lay beyond.

Building the Atmosphere

The balance of constituents in the mostly hydrogen–helium atmosphere (carbon, sulfur, etc.) closely match that in comets, so Toby Owen suggested that the Jovian atmosphere, originally so similar in composition to that of the Sun, has been enriched over the eons by cometary bombardment. (Through the impacts of Shoemaker–Levy 9 in 1994, we see this process happening even now.)

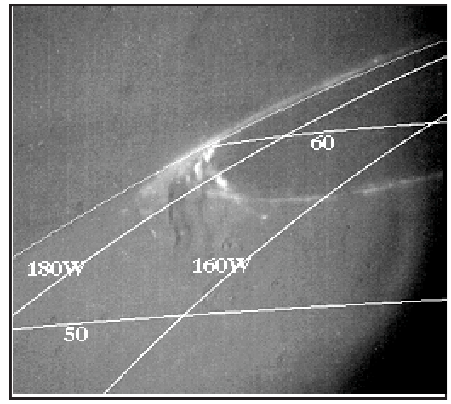
And More

The Jovian Auroras

Also like Earth, Jupiter has auroras. The images that Andy Ingersoll displayed showed a ragged curtain of light circling the north pole where charged particles, streaming down powerful magnetic field lines, slammed into atmospheric molecules in a high, glowing ring some 500 km above the 1-bar level.

Life on Jupiter?

Is there life on Jupiter itself? Toby Owen echoed the consensus opinion that, because there are only clouds and no surfaces, complex molecules would have no place to collect and begin to evolve, but would be cooked when pulled down to the hot mixing level.



The Jovian aurora borealis imaged by the SSI camera in visible light over the night side. The aurora circles the north magnetic pole, reaching down to 57 deg latitude.

—see page 4

Educational Outreach Corner

At JPL, May 20, a warm welcome from Project Manager Bill O'Neil.

Educators fill von Kármán Auditorium to learn about the Galileo Mission.

Scenes From a Galileo Educators' Workshop

The Galileo Mission: Making it Happen workshop featured "take-it-back-to-your-classroom" activities, creative ways that concepts given in the informative talks about how the Galileo Mission works could be conveyed to junior and senior high school students. David Armstrong, 11th and 12th grade math teacher at Marina High School, Huntington Beach, uses our Galileo home page and liked the many classroom applications offered. Bonnie Stefan, 6th grade teacher at Jefferson Middle School, Indio, appreciated the visual and performing arts emphasis. "It was fun!"

Moons orbiting Jupiter.

Europa, B-r-r-r!

Collecting data, a 70-m antenna?

Educational Ambassadors to Jupiter Selected!

Throughout 1997, Galileo's exciting discoveries will be presented to their local communities by **Fred Marschak**, Santa Barbara, CA; **James Beaber**, Lakewood (Denver), CO; **Susan Clavier**, Dover, DE; **Mary Matthes**, Rehoboth Beach, DE; **Charlotte Bihm**, Opelousas (Lafayette), LA; **Don Donovan**, Braintree (Boston), MA; **Betty Paulsell**, Lawson (Kansas City), MS; **Virgil Boehland**, Duluth, MN; **Chelen Johnson**, Minneapolis, MN; **Chuck St. Lucas**, Omaha, NE; **Thomas Estill**, Lyme, NH; **Paul Fisher**, Morristown (Newark), NJ; **Kenn Hitchcock**, Alamorgordo, NM; **John Telesca**, Johnson City (Binghamton), NY; **Bradley Timerso**n, Newark (Rochester), NY; and **Evan Justin**, Vashon Island, WA. These are the 1st-round educational ambassadors selected. The 2nd-round applications will be accepted Aug. 11–Sept. 2.

PROBE MYSTERY SOLVED from page 3

What Does it All Mean?

Understanding Jovian weather is of great value in understanding Earthly weather. Just as medical doctors must understand the comparative anatomy of other animals to make sense of human anatomy, so must meteorologists understand the comparative meteorology of other worlds to make sense of terrestrial weather. Without studying the weather and climate on other planets, there is no way to know just what is peculiar to the Earth, or what may be universal. Jupiter, Ingersoll reflected, is more like the Earth than we thought. But Jupiter is also so much more!

We need more probes!
—Andy Ingersoll

From its broiling, roiling bottomless depths; through multiple cloud decks; to frigid, aurora-lit heights; through endless cloud canyons, searingly dry voids, and centuries-long downpours, Jupiter is an ideal meteorological laboratory.

Our evolving comprehension of this mammoth, kaleidoscopic treasure trove owes so much to the recent, ongoing contributions of the Galileo Orbiter and Probe and also the Hubble Space Telescope, the IRTF on Mauna Kea, Hawaii, and many other instruments and researchers of the Jupiter Watch. But we also have so many more questions. Andy Ingersoll said it best, “We need more probes!” ❖

—Larry Palkovic

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a given satellite “launches” Galileo on its trajectory to the next satellite. Indeed each orbit is a mission in itself. And unlike any other orbital mission to date, every orbit is quite unique. Galileo never repeats its path—it is always in new territory—the ultimate explorer!

On June 25th, we performed the eighth satellite encounter of the primary mission tour—Callisto-9. Save just two days, it was exactly one year from our first encounter—Ganymede-1 on June 27, 1996. All eight encounters—or should I say missions—have been grandly successful. We are eight for eight!

Galileo is now in the seminal magnetotail orbit. Second in size only to the seven-month first orbit, this Callisto-9 (C9) Orbit is taking Galileo ten million kilometers into the magnetotail of Jupiter, where no spacecraft has ever been, in order to sample the fields and particles of this unexplored region to help explain the vastness of Jupiter’s magnetosphere. This journey into the magnetotail has always been a fundamental element of Galileo’s primary mission because it is crucial to one of the three major Galileo objectives, which are to investigate the Jupiter atmosphere, satellites, and *magnetosphere.*

This C9 orbit introduces a new operating feature. At seven key places around this orbit, we are “Recording During Cruise” (RDC). The orbit duration is long enough that we can play back a section of tape, then record new information on that section, subsequently play it back, and repeat this six times. This is particularly important in order to increase the sampling frequency of the fields and particles instruments at these key points in the magnetosphere. The shorter orbital cruise periods of all the other orbits (and greater Earth–Jupiter communication distance, resulting in lower average telemetry bit rates) warrant that we use all of our playback capability to play back the data from the immediately previous encounter.

The Team continues to do a phenomenal job of designing and executing extremely complex sequences, orchestrating the end-to-end data gathering of 11 separate science instruments with very limited (by today’s standards) onboard computing capacity and downlink data rates. All 11 instruments are still providing excellent data even though the Photopolarimeter–Radiometer filter wheel is somewhat impaired, one of the 17 Near-Infrared Mapping Spectrometer detectors is not functioning, and another is problematical. The science bounty of Galileo is already tremendous and growing steadily. The preparations for the Galileo Europa Mission (GEM) that will continue operations through the last day of this millennium are well along. In fact, the planning for the last encounter of the primary mission—Europa-11—has now been made an integral part of the GEM planning, so it’s a series of nine consecutive, synergistic Europa encounters we are planning. And more and more, we are adopting our GEM techniques/procedures as we near the completion of the primary mission so the transition from primary to GEM will be quite seamless.

Congratulations to the Galileo Team that holds the undisputed record for perseverance in space missions and has skills and ingenuity second to none! ❖

— Bill O’Neil

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